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Air Repair

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of these opinions.

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Masking Industrial Malodors

By Breckinridge K. Tremaine
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Wilmington, Delaware

Acknowledgment is hereby given to Dr. L. L. Falk, duPont Engineering Service, and Dr. W. C. Meuly, Research Associate, duPont Company, for contributions to this presentation.

The problem of malodors released to atmosphere has become increasingly important to industry in proportion to its rapid expansion during the last fifty years. The proposals for odor elimination or abatement occupies a prominent part in today's literature, testifying to the vast social and economical importance of this subject.

Voluminous literature dealing with ways and means to decrease malodors indicate that if such odors become airborne the methods of abatement known so far have one feature in common. They are dependent on removal or destroying the odors at a definite point of treatment by physical (e.g. scrubbing, absorption) or chemical (e.g. oxidation; chlorination; burning) means, or a combination of both.

However, this is not always a cure. It often is not practical or as simple as it may sound. The high capital investment involved in erecting equipment, collecting the malodors at a point or treatment at a number of points sharply limits the application of these remedies, particularly in large industrial operations.

Chemical Destruction Best

We believe that destroying malodors by chemical means is still the best method to use, but this involves considerable hardship and expense to those plant engineers and you representatives of civic groups working with industry. Therefore, we in Du Pont undertook the study of the use of industrial odor masking chemicals which could be simply and cheaply applied to change the odor characteristics of malodors which might be considered, prior to treatment, a community nuisance.

We believe we have found a novel and new method which consists of superimposing a more pleasant odor upon a plant odor or the odors that may arise from a stream or lagoon and thus masking their offensive nature. It is evident that to perform this work the industrial aromatic chemical must have chemical stability as often it must resist conditions of processing.

Likewise, it should have proper and graduated volatility to complete its travel through an operation or to be carried into the atmosphere in proportion to the malodor itself. It must be designed to work in aqueous systems, or in systems requiring oil soluble compounds.

It must be strong enough to be used at very low concentrations since the order of odor contamination may represent large volumes of air or considerable areas of contamination.

Time does not allow me to describe in detail the laboratory background covering the investigation and establishment of these important properties, or to explain odor measurement in great detail, or to discuss the laboratory experimental variables studied in testing, such as size of samples, volume of air above solutions, temperatures, solubility factors, aging, requirements of odor free water, use of codes, paneling or the necessity of frequent references to standard samples.

However, it is imperative for you to know that such laboratory background exists and that we have facilities for service to industry for the study of odor problems. We welcome such problems.

How Odors Are Masked

The super-imposing of a more pleasant odor upon a malodor, thus making its offensive nature less objectionable, is often referred to in our work as masking. Before enlarging on the practical aspects of masking, I think it would be advisable to give you some background of how we determine if we can mask a malodor.

This, of course, starts with the measurement of the malodor intensity, as well as that of a suitable aromatic odorant. Odor measurement in absolute terms is not possible because whether simple or complicated apparatus is used, the odor intensity and quality are estimated ultimately by their perception in the human nose.

However, relative odor strengths can be determined. The most extensive method in odorimetry is the dilution of clear odorous air with an odorous gas or vapor until the first often indefinite and vague odor sensations appear. This amount of odor stimulus is called the minimum perceptible or the odor threshold value and it is expressed as a concentration of odorant, preferably in terms of parts per part of air.

This is a yardstick used by many in the field of odorimetry. But we would prefer a simpler method based on diluting odoriferous substances progressively in pure water and smelling the air space above the solution contained in partially filled glass bottles.

It became apparent to us that the minimum perceptible or threshold value method of odor measurement, particularly in industrial work, is subject to great error due to the indefinite nature and faintness of the first perceptible odor stimulation. In our procedure, we determine the Odor Recognition Value, which is expressed as the concentration of odorant, preferably as parts per part of water, at which the odor is faintly but distinctly recognizable.

Such a unit of measurement lies at a concentration about ten times higher than that of the odor threshold

value in water itself and it is much easier to establish and duplicate.

Scent Units Set Up

Once we have our odor recognition value we proceed on a semi-quantitative odorimetric system of measurement which sets up such values as the scent unit, which is the odor stimulus, which produces the faintly but distinctly recognizable odor. This is followed in turn by gram scent value and mask unit value, which expresses the concentration of the odorant at which it causes an odor modification, and finally the mask ratio which is the ratio of the amount of odor being masked to the amount of masking odor.

For example, we have observed aromatic products which when properly compounded and compared to isoborneol, show a mask ratio of 80. This means that the selected odorant or masking agent is a powerful product for abating the odor of isoborneol inasmuch as it will modify an 80-fold amount of isoborneol.

In turn, the mask ratio of isoborneol for the masking agent is only 5, which means that isoborneol modifies noticeably only a 5-fold amount of the masking agent. This yardstick, when applied by those that are trained in the field of odor perception, enables one to quickly recommend the best product or products to offset the nuisance of such malodors as carbon disulfide, hydrogen sulfide, mercaptans, odors from protein wastes, odors from petroleum hydrocarbons, and odors from nitrogenous decomposition which may contaminate our atmosphere either directly from processing or from effluent wastes to streams.

I realize that the above yardstick of odor measurement may seem confusing to many, but truthfully to those closely associated with the odor evaluation, it represents a positive and reproducible means for the selection of the right type of material.

Various Methods Used

Applying the guidance which we receive from our laboratories in the studies which I have just described, we approach the malodor problem practically by applying our products by one or more of the following methods.

1. Spraying, vaporizing, or atomizing the selected odorant into air gas streams.
2. Adding directly to a process whenever possible.
3. Adding to scrubbing liquors.
4. Spreading or floating on contaminated surfaces without dilution.

In the first instance we are dealing with fumes and gases from exhaust systems, usually a stack or vent system, to atmosphere. Spraying, vaporizing, or atomizing a suitable masking odorant into such a system will occasionally prove of advantage, providing the rate of exhaust is below 100,000 CFM. If the rate is greater, the results may vary and often be unsuccessful.

We believe this is because at the higher rate of exhaust the malodors become air-borne so rapidly that the odorant injected into the system has insufficient time to cover and combine, and good odor control is often only possible by using great quantities of odorant which is economically unsound.

Our second point for applying an odorant is directly into a process. Here the odorant must be known to be stable. Application is usually made manually or mechanically based on the process requirements. The odorant can be designed to release to the atmosphere with the malodorous gases or to be retained in part in the system, eventually becoming either a part of the product of manufacture or passing through the operation into the effluent stages.

This is a practice now being followed in the manufacture of Kraft sulfate pulps where the malodors given to atmosphere during gas releases are largely mercaptans. In these operations it is not uncommon to find as much as one or two tons of malodors becoming air-borne or released in part to streams per day. The application of selected odorants in concentrations as low as a few ounces per ton of pulp has proven valuable in the abatement of these malodors.

Scrubbing

Perhaps our third method for treatment, scrubbing, is the best point of application for industrial odorants. They are usually added at low concentrations of one thousandths to one hundredths per cent (.001-.01%) to scrubbing liquors, such as water itself.

For this purpose a soluble type of odorant is used. Waste gases scrubbed with the treated water are quickly changed in odor characteristics and may become masked or abated. Likewise, the effluent waste carried to a stream usually contains a portion of the odorant. Consequently, some odor abatement of the effluent itself is possible.

This method of treatment of malodors is currently being practiced by chemical manufacturers of super phosphates, processors of fish by-products, manufacturers of biotics and petroleum by-products.

The fourth point for application of odorants involves air-borne malodors released from streams and lagoons. The odorants, usually in oil-soluble form, are applied directly to the effluent as it feeds from the industrial operation.

The concentration of a selected odorant, usually sufficient for masking many types of malodors, arising from these sources, is 1-6 p.p.m. based on the total volume of waste. In other words, one gallon of odorant for each million gallons of waste may be sufficient. This type of treatment is being practiced by many plants that are handling wastes from paper mills, textile plants, breweries, canners and tanners.

There is no question that masking agents serve an important function in abating malodors from the above sources. They do not however, influence b.o.d. count one way or the other as far as we have been able to tell. I wish, sometimes, that they did.

However, because such industrial odorants are non-toxic in character, it may be desirable that they show a negative effect.

We feel that the application of masking odorants is a progressive step in helping to improve our community relationship problems.

Low Cost

The cost of using "Alamask" odorants when measured against the cost of alternative odor abatement is generally a great deal less, of course, dependent on the intensity of the malodors which are air-borne, the efficiency of the equipment used, good plant housekeeping, local weather, terrain, and toxicity hazards, if any.

Our pioneering work indicates that fumes from stacks and vents under preferred conditions can be reodorized for a fraction of a cent per million C.F. Odors from streams can be abated at the source at a cost of perhaps a half-dollar per hundred thousand gallons of effluent wastes.

In some instances the cost is even less than this figure. There are, of course, exceptions and in the case of a reodorization program for a large industrial operation in the petroleum industry, or the pulp and paper industry, the total cost may be larger.

There is another phase of any odor abatement program which we believe may play an important part in the fields of odor making. We refer specifically to the study of local weather and with greater knowledge of weather conditions, particularly of temperatures, humidity, inversion levels and turbulence, one may be able to apply industrial odorants at specific periods during operations and obtain lower costs of application with greater benefits.

Charts Used to Illustrate

The utilization of a wind vane and anemometer will provide a continuous record of wind direction and speed as well as the variability of these factors. Previous experience has shown that moment to moment variations of wind direction and speed are good indicators of the state of turbulency of the atmosphere. Atmospheric turbulence is of tremendous influence in determining the dissipation of atmospheric pollutants. The following charts will illustrate this point.

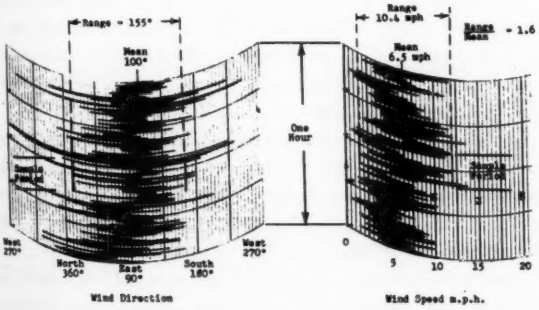

Fig. 1.—Typical daytime wind traces. Strong turbulence.

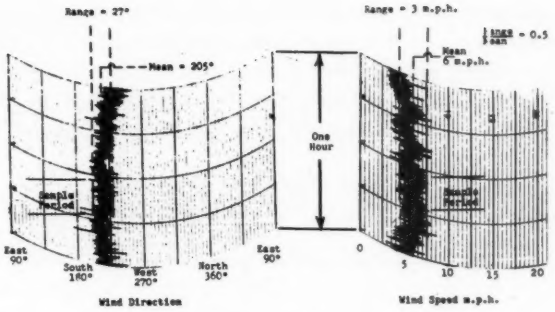

Fig. 2.—Typical nighttime wind traces. Low turbulence.

The first chart shows typical traces from the wind speed and direction recorded during the middle of a warm, sunny day with strong turbulence occurring. Note the large variation in wind speed and direction. Let us compare this first chart with one which shows similar traces at night when turbulence is dampened by stable stratification of air layers in an inversion. (An inversion occurs when the temperature of the atmosphere increases with increasing vertical distance from the surface of the earth.)

The variation of speed and direction at night are considerably less than in the previous illustration of daytime turbulence. The width of the wind speed and direction trace are reasonably quantitative measurement of atmospheric turbulence.

The width of the wind direction trace is representative of turbulence in the horizontal direction while the ratio of the width of the wind speed trace to the main wind speed is reasonably representative of the turbulence in the vertical direction.

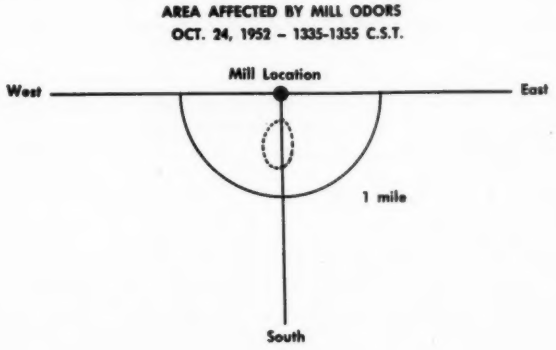

Fig. 3.

With this meteorological information and data from the next series of charts, (Figure 3) when summarized will show you the importance of weather studies. The following charts of odor observations made during six weeks' test period are essentially qualitative and show the downwind distance from an operating plant from which malodors were observed.

The malodor area is within the half circle and is close to operations. It does not extend more than ¾ of a mile from the plant. The half circle or curved lines show the estimated downwind distances for identification of the malodors. The period is mid-day and in dry weather.

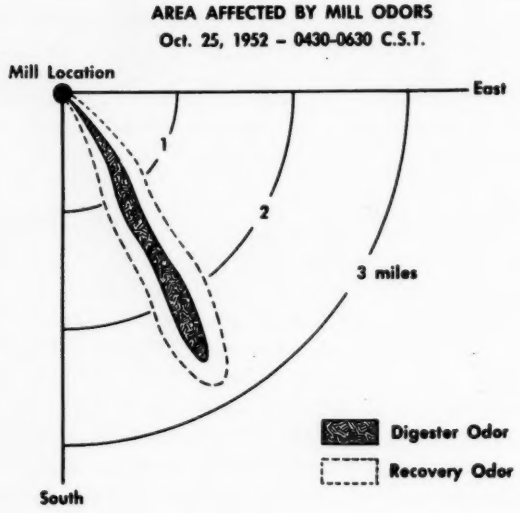

Fig. 4.

In the next chart (figure 4) we observe a pre-sunrise period in dry weather. The malodor extends to a greater distance and is accompanied by odors from typical combustion, not objectionable, which travels slightly further.

The lateral effect is probably caused by the origination of one odor from a line of stacks, the other from a point source. In chart 4A (figure 4A) we observe a post-sunrise dispersion of odor. The noticeable odor extends beyond three miles downwind with faint malodor as far as five miles.

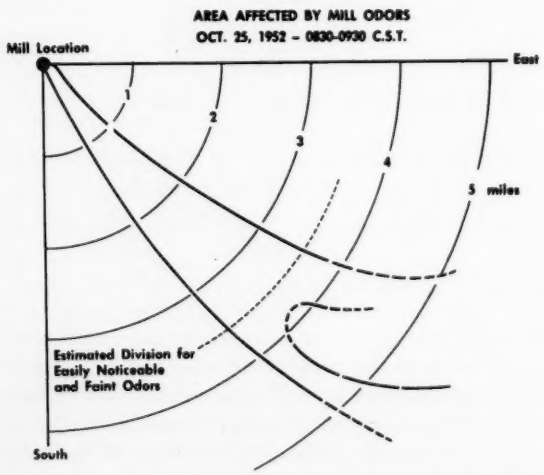

Fig. 4a.

Normal Sequence

The conclusion from these graphic charts prepared to show the normal sequence of odor dispersion from a plant during essentially clear or partly cloudy, dry weather is illustrated in Figure 5. Such weather would be characterized by strong turbulence in the middle of the day, and relative strong temperature inversions at night with little turbulence.

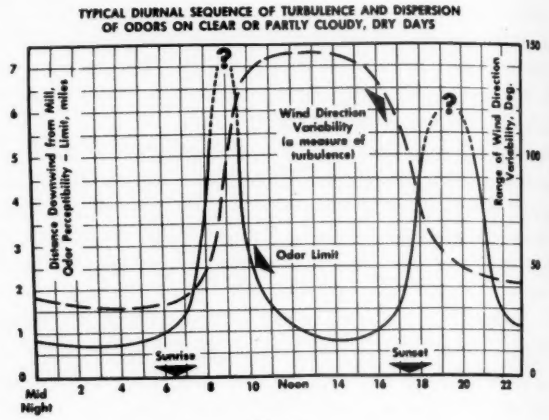
TYPICAL DIURNAL SEQUENCE OF TURBULENCE AND DISPERSION
OF ODORS ON CLEAR OR PARTLY CLOUDY, DRY DAYS
Distance Downwind from Mill, Odor Perceptibility – Limit, miles
Wind Direction Variability (a measure of turbulence)
Range of Wind Direction Variability, Deg.
Odor Limit
Sunrise
Sunset
Mid Night
Noon

Fig. 5.

This generalized sequence of turbulence is indicated by the range of wind direction variability. Let us examine the midnight to sunrise period. The temperature inversion has become fully established by radiation of heat from the surface of the earth.

Turbulence is quite low except for that produced near ground level by movement of air over terrain and buildings. During this period the malodors, at least much of the malodor, probably remains in the air between 100 and 200 feet above the ground level and trails out as a narrow line for several miles. Note the low state of turbulence during this period as indicated by the comparatively low values of the range of wind direction variability.

In the period of sunrise to two or three hours after sunrise a rapid increase in the range of wind direction variability is noted. The increase in turbulent mixing brings to the earth's surface malodorous materials that had been confined to the layers above the surface during the inversion period.

The result is a general fumigation of an area extending several miles down wind from the source and creation of an odor pattern such as shown in chart 4a. Obviously the use of an industrial masking agent would be desirable during such conditions.

In the period of perhaps just before noon to one or two hours before sunset, atmospheric turbulence created by solar heating shows generally high values of wind direction variability range. The depth of the air layers subject to this turbulence may be several hundred feet; thus a considerably larger volume of dilution of air would be afforded the malodorous materials for a given distance downwind.

The result is less detection of malodors, or at least intermittent perception of odor by an observer at a given ground-level distance downwind.

Finally, we observe the period of a few hours before sunset to three or four hours after sunset. During this period turbulence is decreasing as solar heat decreases and radiation from the surface of the earth becomes the predominant factor.

This is characterized by a decrease in the wind direction variability, but not as rapid as the rate shown in the early morning hours. As the turbulence decreases, the amount of air for dilution of odorous materials also decreases, so perceptible odors downwind at ground level would increase.

As indicated the above sequence of dispersion events was determined for meteorological conditions of essentially clear, dry weather, moderate wind speeds 5-10 miles per hour.

In damp, rainy weather tests will probably indicate the diurnal change in turbulence would not be as great nor as rapid. Odor perception would probably be greater and more ground malodor will be obvious. Consequently this is a period when odor masking becomes of great importance.

Once the requirements for odorants based on various weather conditions are established, local weather records can be analyzed for the frequency of occurrence of these types of weather and a more reliable cost estimate for the total masking requirement of a large industrial operation can then be made.

It is our hope that by working closely with industry in the further study of the many factors covering the fields of odor abatement, we can gradually solve many of the unanswered problems which today limit the application of industrial odorants.

If authors wish to have reprints of the papers published in this issue, printing can be arranged by filing requests with Headquarters, which will advise as to cost for the number of reprints desired.

The Counteraction of Industrial Odors

By John von Bergen
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Air pollution has long been recognized as a public hazard, and a cause of serious physical damage to property and to health. Industrial malodors, although sufficiently offensive and objectionable in some cases to interfere with sleep, cause discomfort and nausea, have not often been considered hazardous *as odors* and for this reason insufficient attention has been given to the elimination of these air contaminants until recently.

Quite understandably the greater portion of air pollution control research has been directed to the physiological effect of toxic contaminants and the property damage of particulate materials. Proportionately little research, however, has been directed to revealing the intricacies of odor physiology or the abatement of troublesome odors.

The objective of this paper is three-fold:

1. To place emphasis on the tremendous part that industrial odors play in air pollution problems.
2. To outline the physical, chemical, physiological, and psychological aspects of odor control, and
3. To describe what odor counteraction has done for industrial odor problems and nuisances.

Industrial self-interest in better public relations, the public recognition of depressed property values, and the discomfort aspect of odorous areas have combined to open the doors to an intelligent and logical approach to the elimination of odor problems. It is unfortunate that some of this self-interest has been brought about by the threat of injunction and costly court litigation. On the other hand, intelligent plant management and hard-working public officials realize that definite benefits are to be derived from taking steps to avoid odor nuisance *before* they become noticeable or serious enough to arouse a residential neighborhood.

Symptoms Appear

Once action is started by neighborhood complaints a series of serious developments evolve. McCord mentions the following symptoms: A mild hysteria sets in—Neighborhood witnesses claim damage to household contents, damage to garments, destruction of paint and wallpaper, hens no longer lay, mild dogs become vicious, and automobiles refuse to run.

In spite of the fact that odors as such cannot induce actual organic disease, a whole epidemic of measles has been charged, in one court case, to be the result of odors coming from an industrial plant.

A parallel situation can develop inside the plant. In a labor area where jobs are readily available, employee odor complaints will become grievances, and labor representatives will develop these grievances into demands for more pay for the odorous occupations.

The improvement in the standard of living of employees has made them conscious of their own well-being, not only in the plant, but in the home. Employees often become saturated with odors in the plant, carry these odors in their clothing on public transportation, into the home and into the market.

This situation develops into job dissatisfaction and a high rate of labor turnover. The present day employee is conscious of a desire for social acceptance not only in his occupation but also in the area in which he lives and takes his recreation.

What makes mankind so sensitive to odors? It is probably the millions of years of inherited osmic acuity developed as a necessity for self-preservation as well as for preservation of the species. The odor perception sense is one of the most direct routes to the subconscious mind. A man who has worked in coal dust all his life may walk off the job seconds after he has received a new or obnoxious odor.

Odor Perception a New Field

A very limited number of scientists have directed their attention to the field of odor perception. Around the turn of the century, Hendrick Zwaardemaker, a Flemish scientist, discovered by use of a double olfactometer that two substances, odorous singly, may be *inodorous* together.

Many pairs of odorous substances were introduced individually to either nostril to measure the ratio of quantities required for neutralization or counteraction. By this method all possibility of chemical reaction between the two substances was removed.

Various pairs of counteracting odorous substances were recorded by Zwaardemaker in 1895. Some of the recorded counteracting odors were cedarwood vs. rubber, rubber vs. wax, wax vs. balsam of Tolu, and paraffin vs. wax. It is important to note that the true neutralization or counteraction of odors leaves no overriding odor, pleasant or unpleasant.

There is some confusion in both the technical and popular press regarding the terms odor masking, counteracting, cancelling, and compensating.

Strong odors tend to mask weaker ones. If two odors are of about equal strength, a blend of the two is perceived or possibly both are identified; if one is considerably stronger than the other, it alone as a rule is perceived. This is masking.

On the other hand, certain pairs of odors in appropriate relative concentrations are antagonistic and when the two are sniffed together, the intensity of each odor is diminished. This is counteraction.

The field of odor counteraction, as developed today, is based on the significant work done by Zwaardemaker. The development of odor counteractants has been a pure matter of Edisonian research.

There is no widely accepted classification of odors, and as a matter of fact, the description of odors usually depends upon comparison. Our laboratory has evaluated some 4,000 odors and odor counteractants, and research continues daily.

Industrial odors are complex groups of odors. It is unusual to obtain a specific odor from an industrial process stack and even when this is the case, the odor may combine with transient odors in the surrounding atmosphere. For this reason industrial odor counteractant formulations, although designed for specific odor descriptions, may contain complex groups of odor counteractants.

Odor Objections

The human nose is the most sensitive analytical device known to mankind. Many odors are detected in concentrations of one to ten parts per million. Some of the more noxious odors are perceptible at a dilution of one to ten parts per billion. However, physiological and psychological reactions many times distort the perceptive impression.

Some odors may be pleasant to some people and unpleasant to others. A fair number of persons for long periods of time continuously or continually are beset by odors without the presence of the material ordinarily causing such odors. Most people object to any odor, pleasant or unpleasant, over a period of time, and this marks the significant importance of the desirability of true odor counteraction.

In the practical field of air pollution abatement in the past, the destruction of odors has often had the aspect of a hopeless task. The field of chemical and physical destruction of odors has been explored endlessly. Most chemicals that are known to be effective as powerful deodorants against air-borne odors are too toxic to human beings in the concentrations required for odor destruction in the atmosphere.

The classical experiments of Lister with carbolic acid are an example. Practically every known combination of chemicals has been tried at one time or another in an attempt to destroy odors by chemical reaction. The limitations are extremely restrictive.

The probability of a reaction going sufficiently to completion in low air dilution is limited. Operating problems include conditions of temperature, radiant energy, permissible concentrations of the opposing chemicals, effects on mechanical equipment, relative cost of the several possible agents, and the extreme degree of attention required in operation.

Many Deodorants Irritating

Many of the chemical deodorants devised are irritants, and in some cases such as ozone, with its by-products, extremely toxic. These materials are effective and safe to use only under very carefully controlled conditions which are generally not suitable for everyday living. Some chemicals are effective not only because they combine chemically with the malodor but because they may irritate the olfactory region. Compounds using formaldehyde are an example of the latter type.

Absorption in washes, condensers and scrubbers, although extremely efficient in the removal of particulate material, is not satisfactory in absorbing low concentrations of most odorous gases.

While the high pressure fog nozzle type washer is capable of great air liquid contact surface, a critical point in air capacity is reached where the air stream begins to entrain or carry over the liquid.

Liquids other than water wash may necessitate extensive scrubber construction with expensive corrosion-resistant materials and possibly neutralization or stabilization of the waste water before discharge to the sewer. This poses another problem.

If the water is to be discharged into a stream, the possibility that the dissolved gases may later escape into the air and create a new odor nuisance at a point downstream cannot be overlooked. Precipitron equipment is nearly 100% efficient in removing particulate odorous materials. On the other hand, it is ineffective in removing odorous gases and only a few parts per million of malodors in the surrounding atmosphere are required to contaminate the countryside.

Partial Combustion Ineffective

Combustion is not a method of odor control unless it is complete combustion. The burning of nitrogenous and sulfurous organic material results in the oxides of nitrogen and sulfur. These are not an ideal conclusion to an odor destruction process. Partial combustion is even worse than no combustion. The exhaust from most incinerators will verify this.

A minimum combustion temperature for the complete destruction of refuse, including garbage, meat, corn products, etc., may range from 1400° to 2000° F. Even higher temperatures may be necessary in some industries. The cost of installation and operation usually exceeds the allowable economics in most practical operations.

Mechanical equipment serves an important need in air pollution abatement in eliminating particulate material and its efficiency in regard to particulate material is commendable. Its effectiveness against odors may be compared with the efficiency of the chicken wire screens surrounding a baseball field. The chicken wire screen is 100% effective against baseballs. It is not effective against the molecular dispersion of air-borne odors.

The principle of odor counteraction deals with the molecules of malodor. The application of odor counteraction to industrial stack gases may be the only treatment required or it may be the final step in a multi-stage air cleaning installation.

In extreme examples, the air-borne waste products of an industrial process may contain dust, fume, condensable vapors and uncondensable gases. The entrained material may be scrubbed to remove the dust and soluble or condensable vapors, then passed through an electrostatic precipitator to capture fume and mist particles too small to be retained in the condenser or scrubber, and finally treated by the odor counteraction principle to reduce the highly offensive character of insoluble, non-condensable molecules remaining.

A great number of industrial plants have already installed the best available mechanical equipment to remove particulate substances. In most cases, an odor counteraction treatment is all that is necessary to neutralize the remaining few parts per million of offensive odor and complete the job.

Installation Inexpensive

The equipment required for odor counteraction is installed in a relatively simple and inexpensive manner. The odor counteractant is atomized into the airstream of odorous exhausts by means of a calibrated atomizing nozzle. The counteractant vaporizes and is combined with the airstream by molecular dispersion.

Regardless of the fact whether the stream of the exhaust is held to the ground by air inversion, is vertically dispersed or horizontally dispersed, the counteractant is carried with the malodor and is noticeably effective until the odor is completely dispersed.

In many applications it is not advisable or economically possible to collect the odorous gases for an exhaust stack. In some odorous industries, particularly rendering plants, foundries, and oil refineries, doors and windows are left open or the operation may be spread over a large area.

In these applications the odor counteractant is vaporized in the open near the more important sources of odor and disperses with the odors in the variable airstreams. Large open sludge lagoons and gob piles can be handled in a similar manner without enclosures.

Two important advantages of the odor counteraction application are these; the installation cost is negligible, usually under $150.00 per stack, and the installation can be made in a matter of hours, providing immediate relief from the odor nuisance.

Industrial plants threatened by injunction or completely shut down cannot afford to stay inoperative for the length of time required to make major changes in the process or to install concentrated and expensive mechanical and chemical equipment.

The atomizing equipment is readily adaptable to any stack or working area. It is simple and requires little or no service; it is easy to install; no alterations are required in the process equipment; and no down time is required for installation. The cost of operation is relatively low, averaging about $6.00 per month per 1000 CFM of odorous exhaust on most installations.

No Royal Road

I would like to point out that there is no universal odor counteractant. Odor counteraction formulations are designed for specific groups of odors. Odor counteraction installations should be made by a specialist who can discriminate between odors and estimate the intensity of concentrations.

Although it is rather easy for the trained odor expert to identify characteristic odors, the nose is not particularly sensitive in discriminating between the intensities of concentrations of the same odor. It is necessary in some cases to decrease or increase an odor by 20% to 50% before the nose consistently detects the difference.

For this reason it is usual in applications to operate for 20 or 30 days with an odor counteractant to determine the minimum amount necessary to take care of all variations of odor level and to establish an exact cost of operation. The more intense a specific malodor may be the more odor counteractant is required for neutralization.

An odor counteractant used in industrial work areas or in industrial stacks for control of atmospheric odor pollution should be non-toxic, non-allergenic, non-inflammable, non-corrosive, chemically inactive, economically feasible, and should be effective in the laboratory and in the field.

Odor counteractants should not be used for the control of particulate material nor should they be used where toxic materials exceed the maximum allowable concentration in the air for that toxic material.

I have often been asked, "Once an odor has been treated by odor counteraction, how permanent is the application," or "does the odor return?" The proof of use has been demonstrated over a period of several years.

The company I represent, during the year 1952, treated 2,079 individual cases of odor-contaminated materials to remove the specific odor. In approximately ten of these cases, there was some doubt as to the permanency of odor removal. These cases were referred to independent testing laboratories, such as the U. S. Testing Laboratory. These laboratories reported that, to the fullest extent that the materials could be tested, the odor was permanently removed. There has been no question concerning permanent odor removal in the remaining 2,069 cases and none is anticipated.

Summary

In summary, I wish to re-emphasize the importance of odors as air contaminants. In regard to particulate and toxic air pollutants, there have been conflicts in the philosophies regarding the proper approach to control. The efficiency approach says, "Don't put out anymore than

you have to whether it is harmful or not." The rigorous approach says, "You can put all you like as long as it isn't harmful."

The man on the street or the property owner in a residential district knows little about legislative requirements, dust and mist collection, or evaluation of data. He is armed with the most sensitive analytical device that is known—his nose. He represents public opinion, and when he says, "It stinks," that is air pollution.

Very few odorous industries move into residential districts. On the other hand, new residential districts are crowding around industrial areas every day. For this reason and because of past difficulty in controlling transient malodors, the courts have been reluctant to take action. This situation is changing. With change, in time, comes recognition of the change. We would like to suggest that industrial self-interest, not court action, is still the most desirable approach to the mitigation of odorous air pollution.

The principle of odor counteraction provides a safe, proven, practical and economical method of treating odorous air pollution.

The depressed island around which the city eventually grows can be rehabilitated.

The Use of Sprays to Reduce Stack Emission

By Samuel Radner
Assistant Director, Department of Air Pollution Control,
City of Chicago, Chicago, Illinois

By 1939 an appreciable number of small industrial plants in Chicago had installed spreader stokers. No special dust collecting equipment had been provided. The continuous solids discharge from these plants was reduced by the use of coals of 10 mesh bottom size. However, a considerable number of complaints resulted from the dust discharged during the soot blowing and fire cleaning operations.

In the March 1937 issue of *Power,* Mr. Anthony J. Fette, the Chief Engineer of the Cincinnati General Hospital at the time, described steps he took to abate a neighborhood nuisance caused by his plant. The difficulty, it appeared, was caused by the excess discharge of solids occuring when blowing soot and cleaning fires.

Inside his stack, at 6 feet above the breeching top, he installed a 12 foot diameter ring of ¾ inch brass pipe with 3/16 inch holes drilled on 5 inch centers. He used this to wash out the dust and soot being discharged.

There was as much as a foot of water in the base of the stack after a blow, or close to 1000 gallons. A settling basin was provided outside the stack to settle the solids. Mr. Fette reported that after two years' use there was no evidence of damage to the stack.

Chambers Interested

This method of attacking the problem appeared to have possibilities to the late Mr. Frank A. Chambers, then head of the Chicago Department of Smoke Inspection and Abatement. According to the records he persuaded 11 plants to install stack sprays by September 1939.

Two plants used Mr. Fette's original ring type layout; four used sprinkler head nozzles; and five used single hollow cone nozzles. By 1944 there were roughly 50 such installations. Subsequently no records were kept but it is estimated that approximately 100 such stack sprays were installed, not only in spreader fired plants but in underfeed and chain grate fired plants as well.

In all cases the complaints stopped as long as the spray was used. When complaints were received, investigation disclosed that the spray was not being used either because of mechanical failure or human neglect.

Recently we surveyed 25 plants listed in our records. Of these, 11 had the stack spray still in operation; 14 had discontinued its use, primarily because the plants had converted to low pressure and were not blowing soot; most of these had replaced their spreader stokers with oil or gas firing equipment.

Four plants were still blowing soot with steam or air but had discontinued the spray because they deemed it unnecessary with oil firing. Although we do not agree with this attitude we did not press the point as there were no reports of nuisance from these plants.

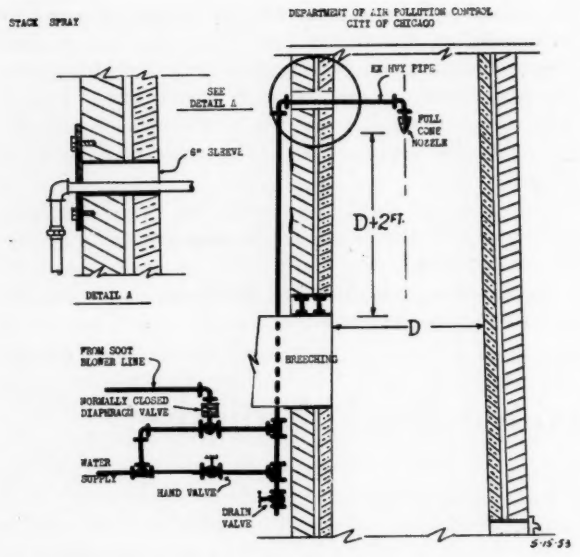
Thus, of these 25 stack sprays installed prior to 1943, 44% were still in use; 40% were rendered unnecessary by plant changes; and 16% were discontinued without consulting the Department. We believe that a substantially greater proportion of the installations subsequent to 1943 are in use as they were in plants of newer equipment less likely to be replaced.

No Loading Tests

No actual dust loading tests were attempted. We doubt such tests would be feasible because of the short duration of the soot blowing or fire cleaning periods. We assumed the collection at the base of the stack increased with the use of the spray.

A checkup with operators indicated this was true but the quantitative data were rather unreliable. Visual observations were made on some of the stacks with and without the use of the spray; these indicated that the Ringelmann density was reduced by one to three numbers.

Some observers reported a deposit of dust on their clothes when standing under the smoke stream during soot blowing without the spray; this did not occur when the



Recommended for reducing fly ash discharge from stacks during flue blowing and fire cleaning periods or other periods during which excessive quantities of solids may leave top of stack. Continuous operation of the washer is not recommended unless a stainless steel lining and adequate drain are provided. The suggested water rates are 0.15 to 0.30 gpm per square foot of stack area; the lower rate for stacks carrying no load during the washing operation; the higher rate for full load condition. Important: A close inspection of the stack lining should be made before installation, faulty joints and cracks should be corrected. When the water pipe is exposed to freezing weather it must be drained each time to prevent damage.

spray was turned on. Observers discounted, in general, the effectiveness of the spray in washing out actual smoke produced by incomplete combustion.

Relatively, the cost of the installation of a stack spray is small; and the operation and maintenance costs are negligible. The greatest opposition stems from the fear of damage to the stack by the impingement of water on the hot stack surfaces and by the corrosion from the combination of sulfur compounds and the water.

By 1943 two cases of damage were reported to the Department. This resulted in a survey of 45 stack spray installations, including the two in question. Only one other stack in this group gave any evidence of damage.

In the first two instances the sprays were installed in round tile stacks serving powdered coal burning equipment and were used continuously to reduce the emission of solids, although one of these plants was equipped with a low draft loss collector.

One plant had 4½ inch sprinkler head nozzles in a 10-foot diameter stack. The other had a ¾-inch hollow cone nozzle delivering 20 gpm in an 11-foot diameter stack. The flow of water in both cases was such that drains and settling tanks were provided. Too, both plants had histories of stack fires before the sprays were put in due to the large carbon content of the settled solids; these fires were thought to have calcined the mortar and made it susceptible to washing.

Tile faces were spalling off and the mortar was being eroded in both stacks. The sensitive spot seems to be above the lintel over the breeching opening.

Spray For Soot Blowing Only

In one of these cases the stack was lined with high temperature cement and the four nozzles replaced by a single solid cone pattern nozzle. The use of the spray was resumed for soot blowing only. No further damage was reported although the refractory lining has to be patched periodically. In the other plant the damage was repaired and the spray use resumed as before until 1950 when a collector was installed in the stack.

In the third case an inspection revealed that the nozzle had corroded and fallen off undetected. Thus large quantities of water were discharged into the stack from an open pipe and caused the brick lining to spall. The damage was repaired, a solid cone pattern nozzle installed and its operation resumed for soot blowing periods.

Subsequently one more case of damage attributable to stack gas washing was reported. A stack spray, controlled by a photo-electric smoke detector was used to control smoke density. After two years of use the engineer found tile faces in the base of the stack. He installed steam-air jets in the furnaces instead to obtain better combustion.

Many of the installations were in lined and unlined steel stacks. Some of these stacks are 20 years old, with the spray in use up to 14 years. No corrosion in excess of normal aging was noted or reported. Some owners discussed the feasibility of lining the stacks with stainless steel up to the level of the spray but only one such installation was made.

In 1950 a spray consisting of 5 small solid cone nozzles was installed in a tile lined stack serving spreader stokers. Tubes are blown, and thus the spray is used, every hour throughout the 24 hours. A calculated 7 gpm is being discharged into an 8½-foot diameter stack, or ⅛ gpm per square foot of stack area. No damage has yet been noted.

Major Deterrent

I dwell on this question of damage because it is the major deterrent to the use of stack sprays. Understandably owners and operators are reluctant to expose such expensive equipment as a chimney to injury. However, from the above experiences we believe that no undue damage to the stacks will occur if:

1) the quantities of water used are not excessive; we suggest 0.15-0.30 gpm per square foot of stack area, the higher rate to be used when the plant is under load during the washing period;
2) the stack walls are not washed;
3) the spray is not used continuously or for long periods.

The type of nozzle best suited for this work has been studied in the field. At this point I wish to express my thanks to both the Spraying Systems Company of Chi-

cago and the Chicago office of the Binks Mfg. Company for their cooperation and help. Experience indicates that:

1) the drilled ring spray reduces washing of the stack walls; however, it produces poor atomization and discharges too much water;
2) the hollow cone pattern spray produces very good atomization but directs too much water toward the stack walls. Observers also report it is less effective than the solid cone spray with equal water quantities;
3) the solid cone pattern spray, although the atomization is not as fine as that of the hollow cone nozzle, directs much less water to the stack walls and produces a more effective washing with a given quantity of water.

Nozzles of brass are mainly used; they are readily available and relatively cheap. They corrode and have to be replaced after 3 to 6 months' use. Steel nozzles corrode and plug up and stainless steel has not proven any more resistant. Therefore, a means of frequent inspection is desirable.

High Pressures Effective

Pressures used range from 20 psi to 150 psi at the nozzles; the higher pressures are more effective with a given quantity of water. The Department recommends 60 psi as a reasonable and effective pressure. Where adequate water pressure for good atomization is not available, compressed air or steam may be used to attain a finer spray. When the spray water is supplied by a reciprocating boiler feed pump, an air cushion chamber should be provided to avoid pulsations in the supply. Otherwise, the washing is likely to be intermittent and puffs of soot and dust will occur.

As soot blowing is generally left to the unsupervised night crew the Department strongly urges making the spray automatic. A normally closed diaphragm valve in the water line, actuated by the pressure in the soot blower line to open the water supply, serves quite effectively. One plant uses an electrical control.

A manual valve, bypassing the automatic valve, makes the spray available for fire cleaning periods and for wetting down the deposit at the base of the stack before that deposit is removed.

When the line to the spray is exposed to freezing temperatures it is essential to drain it after each operation. A ⅛-inch hole in the disc of the drain valve will result in some water loss when the spray is in operation but will insure drainage and avoid possible damage by freezing.

Some engineers recommend the use of hot water, claiming more effective washing. The use of a wetting agent has also been tried, using smaller water quantities. The Johnson-March Company use their Compound M in sprays to wash the discharge from two stacks serving Bessemer Furnaces. Of course, this installation uses many nozzles as well as baffles and drains. Data on the merits of hot water or wetting agents are too meager to be conclusive.

The spray definitely reduces the available draft. In a a five-foot diameter stack a solid cone spray discharge of 7 gpm at 150 psi reduced the draft from 0.30 inches to 0.18 inches. A hollow cone pattern spray reduced it from 0.30 inches to 0.25 inches.

Thus, when soot blowing or fire cleaning is to be done during load conditions, there must be sufficient available draft to offset this reduction; otherwise the furnace or furnaces may be pressurized, endangering personnel and causing smoke. In such cases, where draft is limited, it may be necessary to reduce the rate of fuel burning or even to discontinue it if the spray is to be used.

Summary

The stack spray has proven very effective in reducing the solid emission from stacks during soot blowing and fire cleaning periods, especially in spreader fired plants.

No undue damage to tile or brick linings or unlined steel stacks is expected if the following are avoided: the use of excessive quantities of water; washing of the stack walls; long periods of operation or continuous operation.

To date, experience indicates that a solid cone spray pattern, properly located and sized, is adequate for stacks up to 12 feet in diameter. Pressure of 60 psi at the nozzle is desirable.

If authors wish to have reprints of the papers published in this issue, printing can be arranged by filing requests with Headquarters, which will advise as to cost for the number of reprints desired.

A Study of Gas Distribution in Electrostatic Precipitators

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It is well known by those acquainted with the operation or design of electrostatic precipitators for removing entrained dusts from gases, that uniform distribution of the gas through the treatment zone of the precipitator is essential. This is true not merely because of the obvious possible observation that when the foul gas passes through only part of the treatment zone, that part is overloaded and the rest is relatively idle.

It is also true because of the exponential character of the performance efficiency formula that describes the phenomenon of electrostatic dust collection. Stated in simple form, it has been found, largely by experience, that under a given set of circumstances there is a specific velocity or rate of gas flow that is required to produce a desired cleaning efficiency.

A host of other design factors are of course involved, but the velocity at which the gas is passed through the precipitator is a central and important one. Thus, if design curves show that a desired cleaning result on a given gas is obtainable at a treatment zone velocity of 5 feet per second, the area of the cross section of the precipitator is defined. If, for instance, the volume of gas to be treated is 1,500 cubic feet per second, the cross sectional area of the precipitator treatment zone must be 300 square feet, thus creating a 5 foot per second velocity.

Suppositions

Suppose now that the gas does not pass through the precipitator uniformly but instead moves at a rate much higher than 5 feet per second in some parts of the unit and in other parts at a rate much lower. Even though the average velocity necessarily remains 5 feet per second, the precipitator as a whole drops below its designed cleaning efficiency level.

As has been said, these facts are well known. What is perhaps not so well known is the frequency with which such situations are encountered, and more especially the difficulties that lie in the way of correcting them, particularly if the configuration of the inlet ductwork, which is usually designed and furnished by the purchaser, has been planned without due consideration of the problem of effective gas distribution.

All too often in the past a precipitator manufacturer who has furnished a unit of completely adequate design has been penalized by the necessity for undertaking elaborate corrective measures within his unit to counteract the serious consequences resulting from a poorly designed approach system.

Gas Problem

This paper describes a specific gas distribution problem, and outlines the work done to resolve it satisfactorily. The description is not put forward as basic research in fluid mechanics from which scientific generalizations may be derived. It is rather a description of problem-solving activity limited to a given circumstance, but one for which there are undoubtedly many analogies, so that the experience gained may have general interest value.

The problem arose in a battery of four blast furnace gas cleaning precipitators arranged as shown in Figure 1. The foul gas moves in the 96-inch main labeled "A" as indicated by the arrows. Part of it turns downward in the "T" section of main labeled "B" to enter the manifold marked "C". From the manifold it passes to the individual precipitator units numbered 1, 2, 3 and 4 through the inlet mains and nozzles at "D", "E", "F" and "G". After passing through the precipitators the gas enters the clean gas main "H", moving in two directions to points of use as indicated by the arrows in the main.

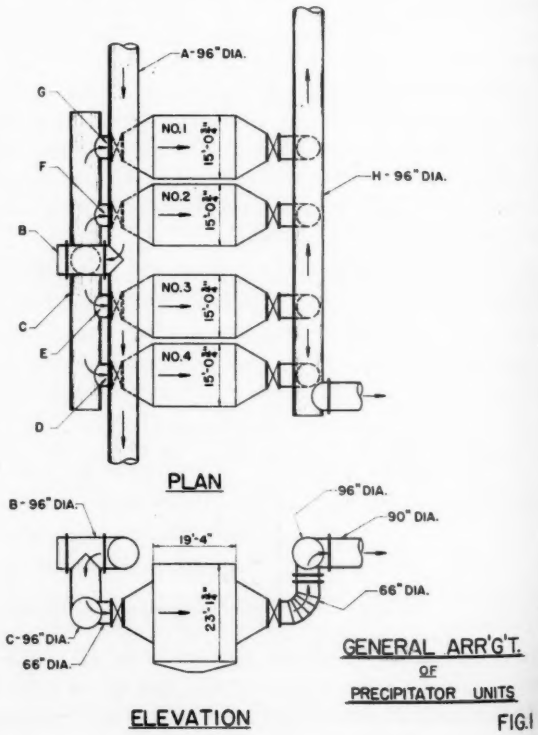


FIG.1

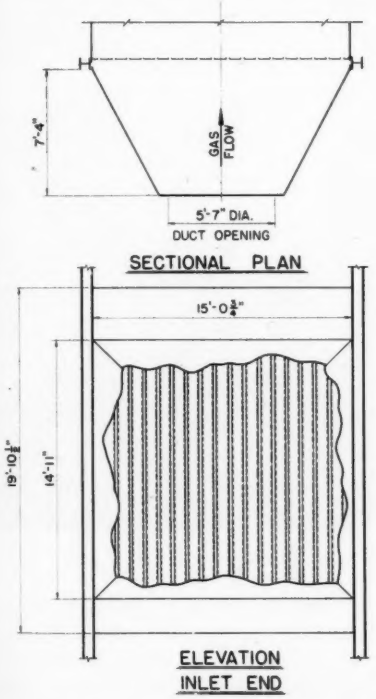
Stated briefly, measurements of dust load in the clean gas main, as well as measurements at the individual precipitator units, showed that there was over twice the amount of entrained dust, on the average, in the cleaned gas as was called for by the design. Where the design indicated a residual dust load in the cleaned gas not to exceed 0.015 grain per cubic foot, actual performance averaged 0.035 or more.

No Flaws Revealed

To limit consideration to essentials, the precipitator units were identical with some in successful operation at other places. Exhaustive analysis revealed no operational flaws, although assumptions were several times made that were subsequently found to be not valid. The matter of proper gas distribution was not overlooked, and the inlet main and manifold arrangement, while symmetrical enough, was known to be different from other installations.

Operating circumstances were such that direct measurement of the gas flow pattern within the precipitator units was not possible. Summed up, it appeared that of all the possible reasons for poor performance, bad gas distribution seemed the most likely, but direct observation of the actual condition could not be made.

Reliance for proper distribution of gas into the precipitator treatment zones was upon a channel arrangement as shown in Figure 2. The channels are placed ver-



CHANNEL TYPE INLET DISTRIBUTOR BAFFLES - FIG. 2

tically in the inlet opening and the gas passes between them, so that it is divided up into ribbons. Each channel is made of two pieces, as though formed of two long angles, lapped over so that the horizontal width of the channel can be varied by the amount of overlap. Thus the width of the ribbons of gas passing between the channels can be varied.

The total space between the channels, through which the gas passes, is called the "through area." As originally installed, the "through area" in the installation was twenty percent of the total inlet area. The remaining eighty percent of the area was, of course, closed off by the channels, the idea being that this restriction would force the gas to spread, and thus go into the treatment zone uniformly.

This arrangement can be effective in one direction only, as the space between the channels is open from top to bottom. The channel method has been used, with apparent success, in other installations.

Corrective Attempts

When it seemed that the channel arrangement was not effective as a distributor in this installation, the first of a number of "cut and try" corrective attempts was made. On the assumption that greater resistance to the flow of the gas would force it to spread more uniformly, the "through area" was decreased to ten percent, by widening each channel appropriately. No improvement in performance resulted.

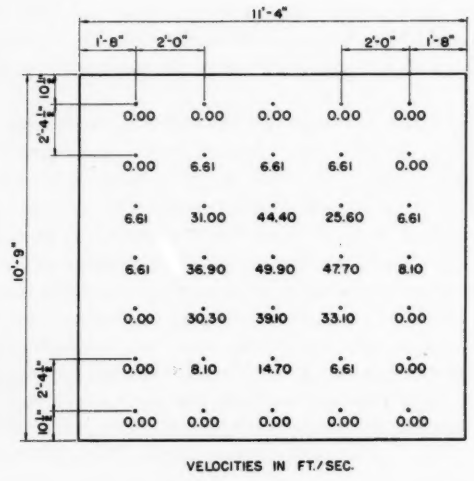
Since it appeared that the channels could be effective in one direction only, another step was to weld horizontal strips across them, so that the gas had to pass through rectangular openings. Through area was kept at ten percent. This resulted in no improvement.

Pitot tube traverses in the inlet nozzles of the precipitator units had indicated that the gas was approaching the distributor channels in a bullet-nose shape. That is, velocities were high at the center, diminishing almost to zero at the outer sides. Figure 3 shows the velocity pattern in a cross section of the inlet nozzle at a point about 3½ feet upstream from the distributor baffles. The nozzles were each 7 feet 8 inches long.

Movable Vanes

With this phenomenon observed, a next step that seemed advisable was to break up the bullet-nose pattern of the gas. This was attempted by installing movable vanes, as shown in Figure 4. These vanes were adjusted to an optimum position by trial and error, and seemed to have some desirable effect. The effect was so small, however, that there was no certainty of a change greater than the possible error of measurement and, in any case, was still far short of the result required.

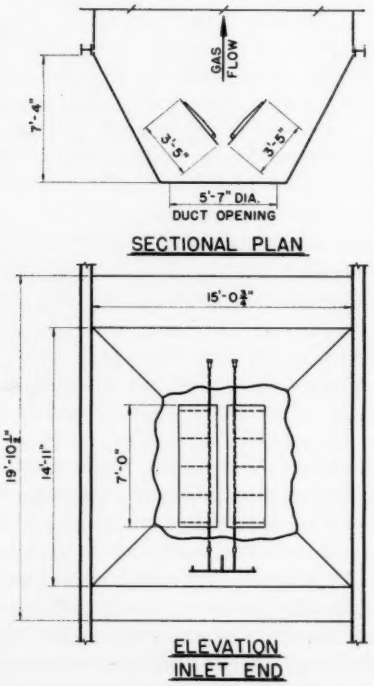
At this stage, it was decided that a carefully designed set of vanes, such, for instance, as concentrically arranged cone sections, might be the answer. A distributor of this kind was actually designed, but what had become evident was that the problem was too complex for cut-and-try attempts at solution. Even if such vaning were the answer, an almost infinite number of arrangements was possible, with the essential question of which arrangement was the right one still far from answered.



VELOCITY PATTERN
INLET NOZZLE-AHEAD OF PRECIPITATOR

FIG. 3

With this realization, it was decided to take the problem into the laboratory. It might be thought that those working on this problem should have arrived at this conclusion before. However, it must be said that previous experience with precipitator gas flow had not indicated the need for such refined observation. Indeed, the available experience indicated that what appeared to be much worse duct arrangements had been taken care of by relatively simple vane or baffle devices.



ARR'G'T OF INLET NOZZLE DIRECTING VANES - FIG. 4

Laboratory Activity

This phase of the laboratory work will be described only briefly. It was in charge of people experienced in fluid mechanics. A 1-to-18 scale three-dimensional water flow model was built, with proper regard for dynamic similarity through Reynolds Number calculations. Fig. 5 shows the general arrangement of the water flow model.

A normal course of investigation was followed, beginning with observations of the flow pattern produced with the original installation, and continuing with varying distributor arrangements designed to improve the observed flow patterns. The first important conclusion that could be drawn from the water model study was that the flow pattern was indeed very bad, with wide variation in velocities, and with indications of reverse flow in some areas.

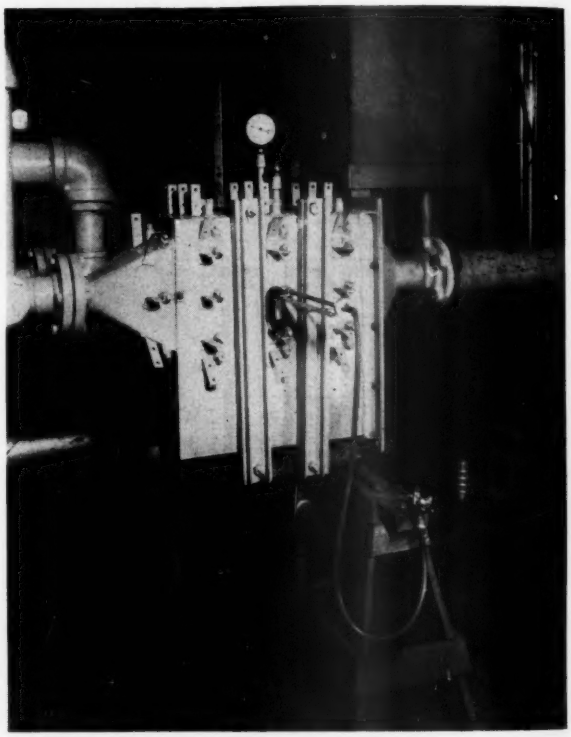
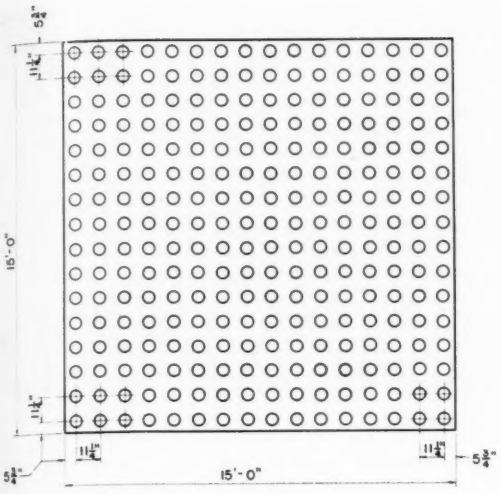


Fig. 5.—Water flow model—1/18 scale.

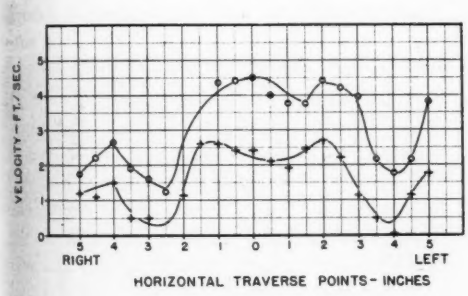
Considerable improvement was obtained by covering the inlet opening of the precipitator model chamber with a perforated plate in place of the channel baffle. No vanes were used in the inlet nozzle. Figure 6 shows this plate. The holes were uniform in size and uniformly distributed. The through area provided by the holes was twenty percent. In the commercial unit an equivalent plate would have been 15 feet square with 5½ inch diameter holes on 11¼ inch centers.



PERFORATED DISTRIBUTOR PLATE
20% THROUGH AREA

Fig. 6.

Although this plate gave an improved flow, the observed velocity profiles were still irregular, showing a "W"-shaped pattern generally as indicated in Figure 7.


o — ENTRANCE VELOCITY = 20.1 FT./SEC.
R (INLET PIPE) = 464,000
+ — ENTRANCE VELOCITY = 11.6 FT./SEC.
R (INLET PIPE) = 268,000
VELOCITY - FT./SEC.
RIGHT
LEFT
HORIZONTAL TRAVERSE POINTS - INCHES

VELOCITY PROFILE
WATER FLOW MODEL

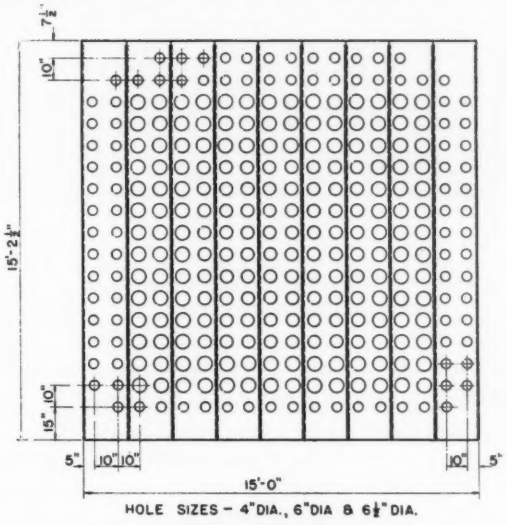
Fig. 7.

Figure 7 is only representative, but illustrates the conclusion that ". . . the flow pattern obtained with the perforated baffle plate with twenty percent opening consists generally of a central jet, a surrounding low velocity region, and large velocities again at the section boundaries."

Hole Sizes Varied

From analysis of this type of velocity profile, it was decided to vary the hole size in the twenty percent perforated plate in a suitable way. The rows of holes around the outside edges of the plate, where the high velocities existed, were made smaller, to restrict flow. The holes in a square section at the center of the plate were also made smaller, to restrict the highs there.

In the intermediate areas, where the profile exhibited low velocity valleys, the holes were made larger. This effort ultimately resulted in a plate much as shown in Figure 8. At prototype size this plate would have been 15 feet square, the outer holes would have been 4 inches in diameter, the intermediate ones 6½ inches in diameter, and the central ones 6 inches in diameter.



NON-UNIFORM
PERFORATED DISTRIBUTOR PLATE
23% THROUGH AREA

Fig. 8.

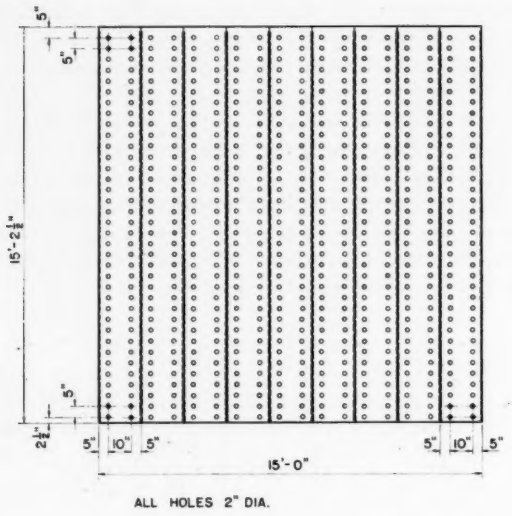
In the model study this plate showed such an improved flow that it was thought the solution to the flow problem had been reached. As a consequence, a full-size plate was fabricated and installed in two of the four precipitators. It was somewhat discouraging to find that no improvement in the performance of the precipitator resulted.

Opinions Differ

While it is generally agreed that water-flow models are suitable for investigations of this kind, there continues to exist a difference in opinion as to the results of this particular study. One opinion, roughly stated, is that the study was on the right track, but had not been carried far enough.

The contrary opinion is that if the improvement shown in the model had been valid, some improvement should have resulted in the prototype, even if the desired result was not completely attained. This opinion held, roughly,

that the great reduction occasioned by the 1-to-18 scale introduced complications that biased the whole effort. It must be added that both opinions were of hindsight nature.



PERFORATED DISTRIBUTOR PLATE
6% THROUGH AREA

FIG. 9

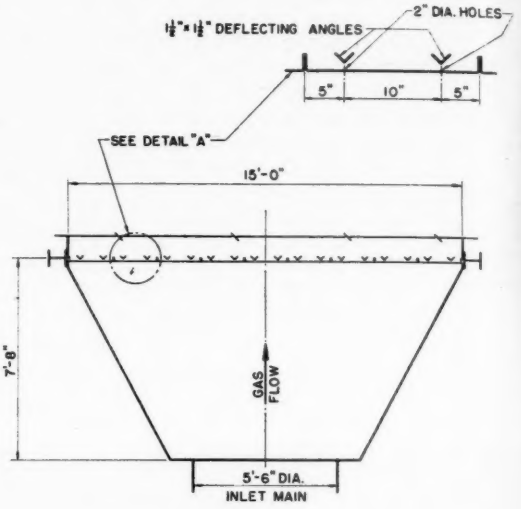
Faced with another failure, those responsible for the work executed a sort of desperation move. On the assumption that back-pressure was a primary factor in attainment of uniform flow, it was decided to install a distributor plate designed to the limit of allowable pressure loss. This loss was established as 2 inches water column, and the resulting plate is shown in Figure 9.

The holes in this plate were 2 inches in diameter, were on 10-inch centers, and provided a total of about six percent through area for gas passage. With such a restricted passage it was evident that gas flow through the holes in the plate would be at a high velocity, with jet action as a consequence.

This supposition was verified in a rough laboratory check, so a method was devised to break up the jets, of which a plan view is shown in Figure 10. One and one-half inch by one and one-half inch angles were mounted with their V's about one inch downstream from each row of the holes in the perforated distributor plate. This device was tried out in the commercial installation, and once again the result was failure. If anything, the resulting performance was worse. The jet-breaker angles were removed, but no difference was observable.

Back to the Laboratory

At this point the decision was made to put the problem back on a laboratory footing, but this time to build an air flow model of the largest practicable size. A one-third scale was decided upon, which made the cross section of the model 5 feet square, the foul gas main and manifold 32 inches in diameter, and the inlet mains 22 inches in diameter. The resulting structure is shown in Fig. 11. The model was faithful to the prototype, although only one-half of the manifold and one of the four precipitator units were reproduced. Openings were provided to simulate flow into a parallel unit. Other openings were provided in the manifold end, just beside the right shoulder of the man in the illustration, and in the end of the foul gas main above his head, to provide flow components as they existed in the actual installation. The scale size of the model indicated a velocity through the model chamber of 9.6 feet per second. Total volume was 240 cubic feet per second. Reynolds Numbers for model and prototype were of the order of 1,000,000.



SECTIONAL PLAN

ARRANGEMENT OF 6% PLATE
WITH
DEFLECTING ANGLES

FIG. 10

On the side of the model are two vertical rows of couplings and plugs. The row nearest the inlet manifold was placed downstream from the location of the inlet air distributor plate as far as permitted by the internal components of the precipitator. The other row was placed at the precipitator center; that is, halfway between inlet and outlet.

Flow measurements were taken by passing a pitot tube into the unit through these holes. As the study progressed it was found necessary to traverse only at every other hole. From top to bottom hole this made eleven traverses. At each traverse twelve readings across were taken, re-

Fig. 11.—Arrangement of air flow model.

sulting in 132 readings in each plane for each observation. For the basic study about 15,000 such readings were taken, and about 725 velocity profile curves drawn from the data recorded.

Visual Observations

The other side of the model has the plexiglass inspection windows that were provided. (Fig. 12.) The "U" tube manometer that can be seen showed pressure drop from a point in the inlet main to a point in the outlet main. In a vertical plane across the inside of the model, at about the location of the inspection ports to the right, were rows of wire to which short light pieces of string were tied. These strings provided a rough visual observation of the air flow, and proved to be of great value. Some of the pitot tube measurements might not have been believed had the strings not been there to give at least rough confirmation.

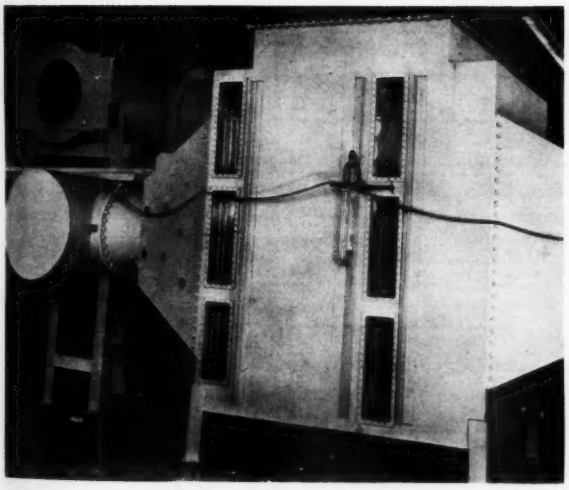


Fig. 12.—Air flow model.

All internal components of a precipitator that could conceivably affect gas flow or distribution were included in the model. Chief among these were the flat plate collecting electrodes, which were placed in proper number. Fig. 13 shows the motor and blower arrangement.

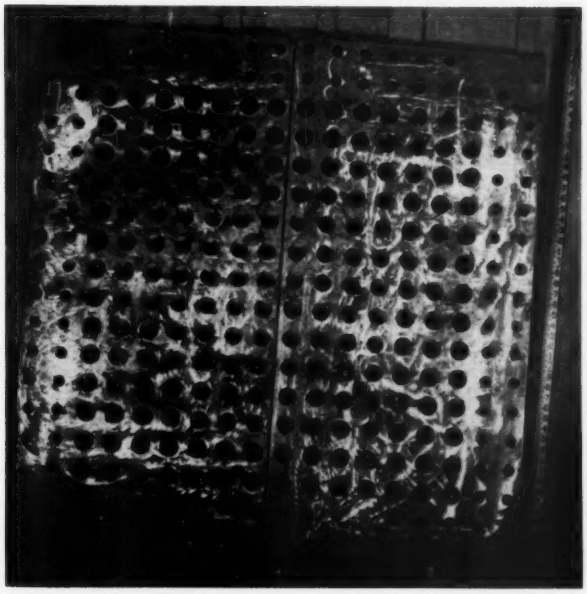
Fig. 13.—Motor and blower—air flow model.

The motor was 150 horsepower, 1750 r.p.m. at full load, and the fan capacity was 45,000 c.f.m. at 1750 r.p.m. and one inch H_2O static pressure. Pitot tube measurement points were located at various places in the main and manifold system, and barometric pressure and duct temperature were regularly recorded.

700 Curves Drawn

From the fact that over 700 curves were drawn from

Fig. 14.—23 percent perforated distributor plate.



data recorded in the study, it is obvious that only significant or representative results can be set forth here. The study progressed normally, beginning with observations on a completely empty unit, and progressing through one change or addition at a time, adhering to the principle of the single variable.

All of the distributor plates heretofore mentioned were tried out, and others developed and tried. Readings were taken in the precipitator chamber at the end and intermediate manifold positions. Every notion that occurred to any of those working on the study was given a chance, as were the ideas contributed by a considerable number of visitors. Fig. 14, for instance, shows the distributor plate with varying sized holes and a 23% through area that had resulted from the water-flow model study. Fig. 15 shows the high back-pressure plate with the 6% through area, as seen from its downstream side. Five of the jet-breaking angles are left in position in the figure, concealing the holes in that portion of the plate.

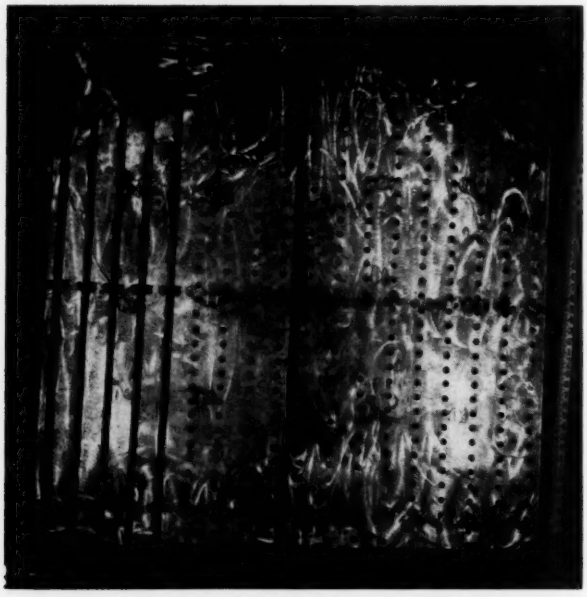
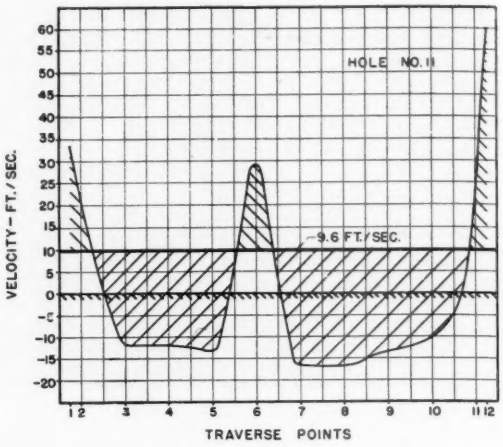


Fig. 15.—6 percent perforated distributor plate.

Conclusions

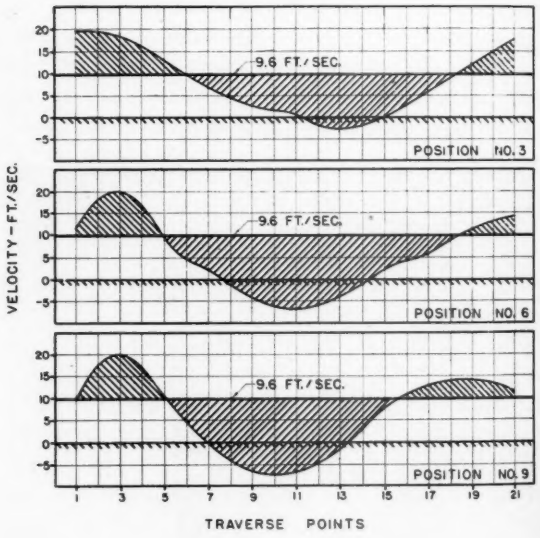
Some of the conclusions drawn from the earlier stages of the study can be enumerated:

1. With no distributor plate in the unit, the flowing air piles up along the side farthest in the direction of flow. In the center of the unit, and at its near side, there was negative or reverse flow. Some type of distributing means was obviously necessary.
2. All types of distributors that accompanied poor performance in the prototype showed poor air flow in the model. The notes on the run with channel type distributors set for twenty percent through area, for example, read, "Flow extremely unstable. Regions of very high velocities and negative velocities were observed." A single velocity profile drawn for the six percent through area perforated plate is also illustrative, as shown in Figure 16. While figure 16 should not be taken to mean that all of the several hundred profiles of unsatisfactory flow were of exactly this shape, it does illustrate the variation and instability that was observed. Note that while the point of average or design velocity was just under 10 feet per second, variation existed from as much as 60 feet



HORIZONTAL VELOCITY PROFILE
6% THROUGH AREA
PERFORATED DISTRIBUTOR PLATE

FIG. 16



VERTICAL VELOCITY PROFILE
VARYING HOLE-23% THROUGH AREA
DISTRIBUTOR PLATE

FIG. 17

positive to more than 15 feet negative. Note especially that negative readings indicate an actual reverse flow. Observation of the strings mounted in the model in such cases was very useful, in that some strings were extended downstream and others equally persistently pointed upstream. A sample of the velocity profiles developed for the distributor plate that gave best results in the water-flow model is shown in Figure 17. While the fluctuations are not so extreme as in Figure 16, the same general circumstance of variation and reverse flow may be seen.

3. The third of earlier general conclusions concerned the effect of a distributor plate at the precipitator outlet. It is common practice in precipitator design to install distributor plates both at the inlet and outlet ends of the precipitator. Observations in this study led to the conclusion that the outlet distributor had no measurable effect on the flow pattern through the model. While no generalizations were made, it was accepted that for the circumstance under consideration the outlet distributors could just as well be removed entirely.

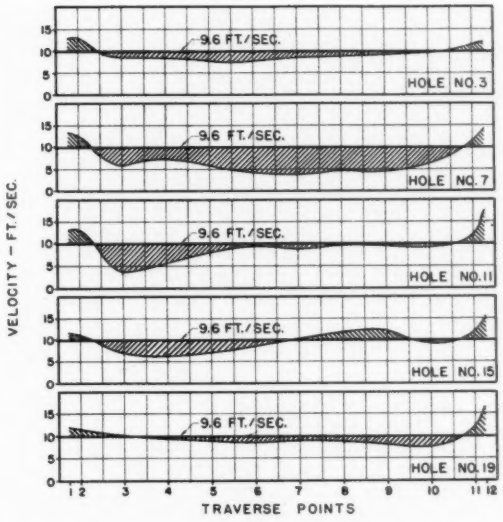
With the conviction that none of the gas distribution devices that had been tried in the prototype could be counted on to produce particularly good gas flow, the development of better ones was started. From the observations already made in the study, and from analogous work done by others, several assumptions served as guides.

These were:

1. A perforated plate with uniformly sized round holes uniformly spaced seemed to offer good possibilities.
2. A too-restricted through area seemed to make flow less stable so that the indicated direction was toward greater through area.
3. Several distributor plates in series might be more productive of desired results than refinement of a single plate.

The study then proceeded in the direction indicated by these assumptions which, incidentally, were found to be valid. Runs were made using uniformly spaced round-hole perforated plates with through areas of twenty, thirty, forty, fifty and sixty percent. Various combinations were tried, such as three twenty percent plates in series, or two forty percent and two sixty percent plates in series.

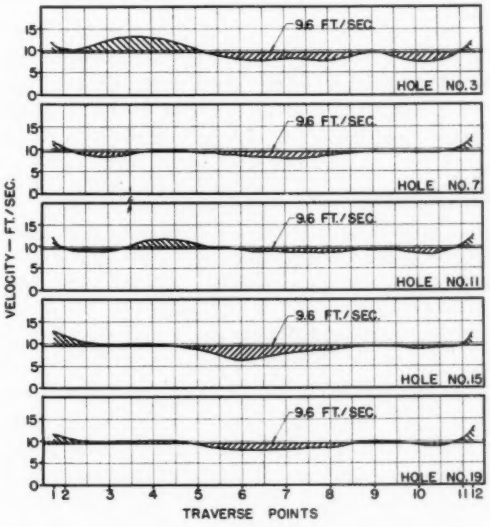
Recalling Figures 15 and 16, the results obtained with three thirty percent plates in series indicate the progress made. Figure 18 shows a sample of the profiles produced with three thirty percent plates. The curves are relatively flat, and there is no reverse flow. It should be noted here that one of the observations in the study that was interesting but entirely subjective was the ease or difficulty with which readings could be taken. With such flow as illustrated in Figures 15 and 16 the draft gauge was difficult to read. With flows such as shown in Figure 18 the gauge was steady and readings could be taken rapidly.



HORIZONTAL VELOCITY PROFILE
THREE PLATES IN SERIES
30 % THROUGH AREA EACH PLATE

FIG. 18

Optimum results were finally obtained with four forty percent through area plates in series, and it was observed that an increase in through area to fifty or sixty percent gave less stable results. Figure 19 shows a sample of the velocity profiles produced by four forty percent plates in series. It appeared evident that these results were about as good as could be obtained without disproportionate



HORIZONTAL VELOCITY PROFILE
FOUR PLATES IN SERIES
40 % THROUGH AREA EACH PLATE

FIG. 19

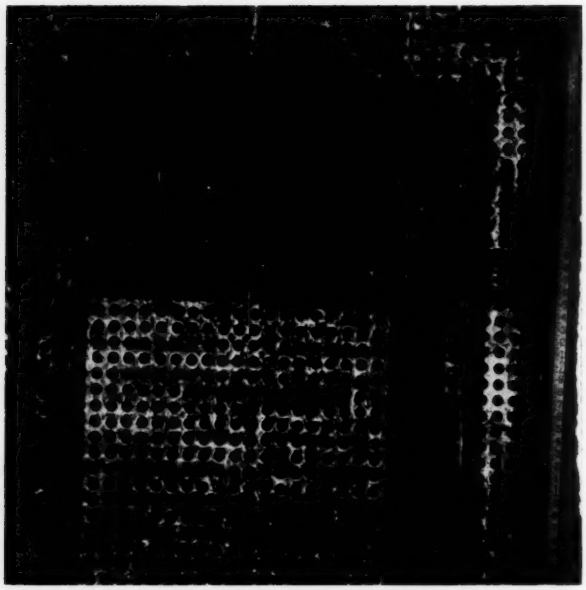
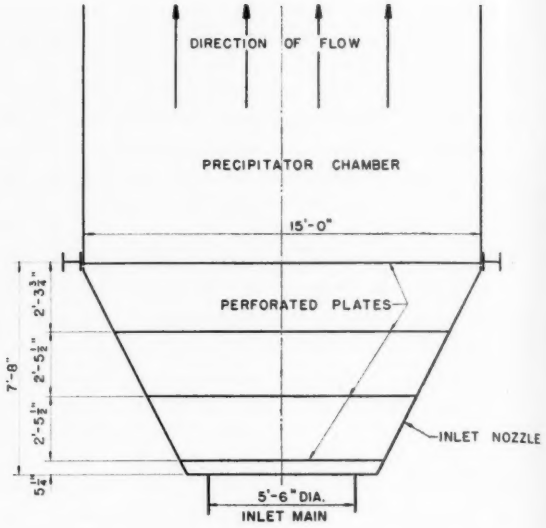


Fig. 20.—Four 40 percent through area distributor plates.



LOCATION
OF
FOUR-40% PLATES
IN PRECIPITATOR INLET NOZZLE

FIG. 21

expense and complexity, so they were accepted as the next to be tried in the field. Figure 20 is a photograph of the set of four forty percent plates used in the flow model.

One further matter had to be determined. When the plates are placed in series, the distance between them is of consequence. The spacing used in the model was ten times the diagonal distance between the holes in the plate, which is a rule-of-thumb in this type of work. Varying the spacing indicated that while changes of small magnitude made no measurable difference, the rule-of-thumb held. The rule indicated a 10-inch spacing in the model, and an 8-inch spacing gave measurably poorer results. Space limitations prevented an observation of the effect of spacings much greater than 10 inches, but variations began to be of low magnitude.

Figure 21 is a sketch showing the way the distributor plates were installed in the precipitators in the field.

The final chapter of the story is probably best told in the results obtained from performance tests run after the four forty percent through area distributor plates were installed in the precipitators. The maximum amount of dust that was to be permitted in the cleaned gas was 0.015 grains per cubic foot. Prior to the installation of the set of four distributors the dust content averaged 0.035 grains, or more than twice the desired maximum. After installation of the plates the dust content dropped to the order of 0.007 grains per cubic foot, or well below the 0.015 top limit, and has remained at that level. The pressure drop resulting from the four plates was less than one inch W.C.

As stated before, this discussion does not attempt to go beyond a brief description of a problem-solving activity concerning the effect of gas flow on the performance of electrostatic precipitators in a particular installation. The problem was solved, and considerable other flow work not directly part of the problem was done. It would appear that the general field is worthy of further investigations.

Electrical Resistivity of Fly Ash

By H. J. WHITE,
Research Corporation, Bound Brook, N. J.

Electrostatic precipitation has long been accepted as a standard method of dealing with air pollution from industrial sources. These sources usually involve large gas-flow rates, high particle concentrations, high gas temperatures, and other difficult operating conditions.

This paper deals with an important phase of research in one of the largest fields of electrostatic precipitation, the removal of fly ash from pulverized-coal-fired boilers in the power-generation industry.

Although public attention has been increasingly directed in recent years to air pollution and its sources, the public utilities early recognized the problem, and since 1923 electrostatic separators have formed an integral part of most power-boiler installations fired by pulverized coal.

It is particularly significant to note that the utilities have provided collection equipment giving performance well above accepted standards such as the ASME Code.

The present extent of the fly-ash problem is strikingly shown by figures on the pulverized coal burned by utilities in this country which indicate that as much as 10,000,000 tons of fly ash[1] could be emitted annually if no collection equipment were used.

As a specific example, a single large modern boiler producing a million pounds of steam per hour will typically exhaust 100 tons of fly ash per day. The effectiveness of the electrostatic precipitation method in coping with this problem is indicated by the fact that even the first installation of thirty years ago gave an efficiency of 90%, and the figure has climbed steadily since then, with many present-day installations providing efficiencies in the range of 95% to 99%.

Many Problems Solved

The successful application of precipitators in the fly-ash field over a period of many years, under conditions of constantly increasing gas flow and efficiency requirements, together with the trend toward the burning of poorer-grade coals, has required the solution of many difficult problems. [2] [3] [4]

"Electrical Resistivity of Fly Ash" was chosen as the subject of this paper because it provides a good illustration of the advances which have been achieved in recent years through the application of fundamental research to these problems.

Role of Particle Conductivity in Electrostatic Precipitation

In the Cottrell process of electrostatic precipitation of suspended particles in gases, a small but definite unidirectional flow of gas ions emanating from the region of the highly charged corona electrodes must continuously pass through the deposited dust layers in order to reach the collecting electrode surfaces. Therefore, this deposited dust must possess at least a small degree of electrical conductivity in order to pass the necessary corona current and to avoid disturbing effects.

Most of the dusts and fumes encountered in industrial gases, including fly ash, are composed of oxides, silicates, and other similar inorganic compounds which in the pure state are characterized by a high degree of electrical resistivity.*

Fortunately, in the majority of cases chemical impurities and moisture are present naturally in the gases and on the particles to an extent sufficient to provide the small degree of conductivity required for the electrical precipitation process.

However, there are certain fumes and some dusts which are either borderline or critically lacking in these natural conductivity substances and which require the use of artificial conductivity or conditioning agents in order to ensure normal precipitator operation.

Theory, experiment, and field experience all show that the critical maximum value of resistivity of the deposited dust layers is about 2×10^{10} ohm-cm. Above this value, precipitator operation tends to become sub-normal because of the onset of intensified sparking or, in severe cases, because of the occurrence of so-called "back corona" or reverse electrical discharge from the collecting electrode surfaces.

Measurements made on a wide variety of fly ashes under actual field conditions give normal values of resistivity ranging between 10^8 and 10^{10} ohm-cm. A limited number of ashes, however, are found to be in the region of 2×10^{10} ohm-cm, where precipitator trouble is a possibility, and a few in the region of 5×10^{10} ohm-cm, where trouble is virtually certain.

Chemical compounds which in small quantities greatly reduce dust resistivity are designated "conditioning agents," and have been used in electrical precipitation for many years. In general such compounds are specific for each type of dust or fume, although some conditioning agents are effective for a number of materials.

Field values of the resistivity of fly ash for a wide variety of boiler operating conditions and installations, together with accumulated experience in the operation of fly-ash precipitators, indicate that some type of chemical conditioning agent is present naturally in most boiler gases.

*Resistivity is defined as the inverse of conductivity, and is a term frequently used in the electrical field when dealing with poorly-conducting or insulating materials. The cgs unit of resistivity is the ohm-cm. In practice, one may think of resistivity as being equal to the resistance measured between opposing faces of a 1 cm cube of the material.

Identification of the specific conditioning agent present, together with the factors which determine its effectiveness, are matters of great practical importance, both for understanding the phenomena involved and for determining the measures required to correct or improve the operation of those installations where high-resistivity ash is encountered.

Thus there is much more than scientific curiosity involved. One is dealing with fundamentals which must be understood and controlled in order to provide effective application of the electrostatic precipitation process to practical problems.

Measurement of Fly-Ash Resistivity

Quantitative laboratory work on fly-ash resistivity and its effects on electrical precipitation was begun by the author in 1937 and was followed by field work on large precipitator installations beginning in 1940. These early studies provided a general picture of the range of magnitudes possible for fly-ash resistivity and also of the physical conditions on which the resistivity depended. Unfortunately it was necessary to interrupt this research during World War II, and no further work was possible until the project was resumed in 1946.

The early laboratory measurements were made using the specially designed high-voltage conductivity cell shown in Fig. 1. This cell was mounted in an electrically heated and thermostated oven in which the temperature could be raised and controlled up to values of about 750 F.

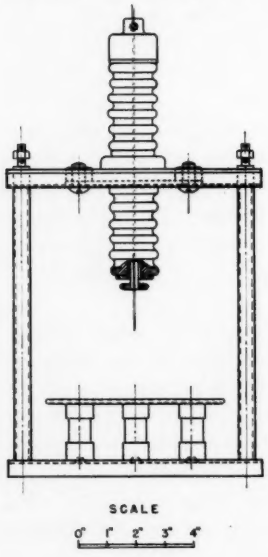


Fig. 1

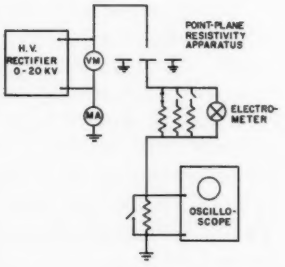


Fig. 2

In subsequent studies, arrangements were also provided to control the humidity as well as the temperature of the air in the oven. The electrodes of the cell were connected in series with a sensitive galvanometer or electrometer, oscillograph, and high-voltage source, together with the necessary switching and shunting devices as illustrated in Fig. 2.

Using this apparatus, the resistivity of a dust sample may be determined by two independent methods. In one method a sample of dust several millimeters thick is placed on the grounded plate and the high-voltage disc-electrode is lowered to make light contact with the layer.

The voltage is then gradually raised to the point where sparkover occurs between the disc and the grounded electrode, the current being observed continuously by means of the galvanometer or electrometer. The resistivity is then calculated from the dimensions of the conducting dust layer and the current and voltage applied to the cell just before sparkover occurs.

In the second method, the dust layer is formed on the ground electrode as before, but the corona-point electrode is used instead of the disc. Again, the voltage is slowly raised to the value at which the corona current makes a sudden or discontinuous jump and a luminous back-discharge crater appears simultaneously in the dust layer.

The value of the corona current density through the dust layer just before the current discontinuity then corresponds to the breakdown current density for the dust layer, and this theoretically should be equal to the value obtained by the first method. These two independent methods enable one to check the accuracy of the measurements, and also to study a broader range of phenomena.

Laboratory Measurements

A typical resistivity-temperature curve for fly ash is illustrated in Fig. 3. The resistivity is observed to be of the order of 10^9 ohm-cm at room temperature, rising rather steeply to a maximum of about 10^{13} ohm-cm at 120 C, and then falling with further increase in temperature, again reaching a value of 10^9 ohm-cm at about 375 C.

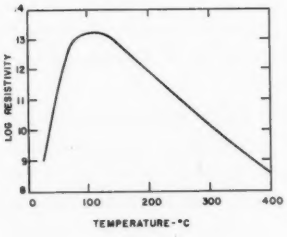


Fig. 3

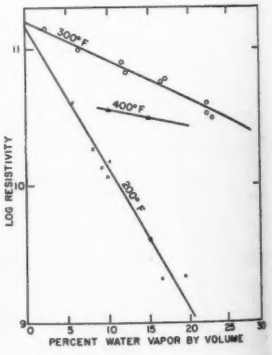


Fig. 4

The general form of the curve may be explained as follows. At room temperature the ash particles adsorb considerable moisture from the atmosphere and therefore have a relatively low resistance. The effect of adsorbed moisture films in increasing conductivity on insulator surfaces is of course well known.

As the material is heated, the adsorbed moisture is driven off and the resistivity rapidly increases. The falling section of the curve may be explained on the basis of temperature or ionic conductivity[5] in the particles, also a well-known phenomenon in insulating substances.

The maximum value of resistivity occurs at the temperature at which the decrease in conductivity due to loss of moisture from the particle surfaces is counterbalanced by the increase in conductivity due to rising temperature.

The resistivity measurements shown in Fig. 3 were made in an oven using atmospheric air with a humidity of the order of 1% by volume, an amount insufficient to materially affect dust conductivity at temperatures much above atmospheric. Boiler gases on the other hand usually have a much higher moisture content of the order of 5 to 10% by volume.

Laboratory measurements of resistivity for these higher humidities are shown in Fig. 4. It is interesting to observe that the effectiveness of moisture in reducing resistivity is much greater for the lower gas temperatures.

For example, at 200° F resistivity of the ash decreases markedly with increasing gas humidity, while at 300° F the effect is much less pronounced, and is almost negligible for temperatures in the region of 400° F or higher.

These results may be explained qualitatively in terms of the amount of condensed moisture on the particles, which increases with the vapor pressure of the water in the air, but decreases rapidly with increasing gas temperature.

Field Measurements

Field measurements of particle resistivity in power station flues have been carried out using an apparatus similar in principle to that used in the laboratory but designed particularly for compactness and light weight.

The point-plane resistivity probe for field use is illustrated in the photograph of Fig. 5. Practical considerations call for a device which can be conveniently inserted in the gas flue through an ordinary 3-inch pipe coupling.

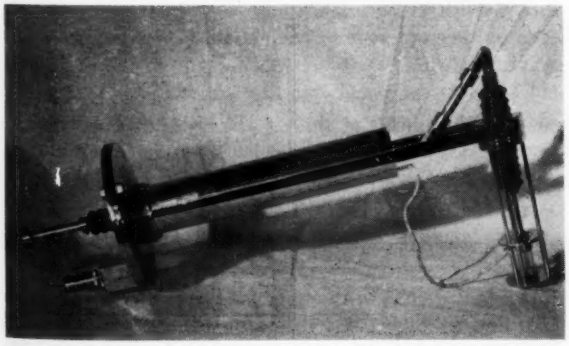


Fig. 5.—Point-plane resistivity probe used for field measurements.

Position of the high-tension disc electrode is controlled externally by means of an insulating Fiberglas string passing through the hollow high-tension conductor. In operation it is necessary first to collect a layer of ash at least several millimeters thick on the plate electrode.

This is accomplished by applying a voltage of the order of 10 kv to the corona point for a period of 20 to 40 minutes, which causes collection to occur by the normal electrostatic precipitation process. The resistivity of the collected layer is then determined, using either or both of the techniques previously described in the discussion of the laboratory methods.

A summary of typical field values of fly ash resistivity obtained using this apparatus is given in Table I. Values of resistivity are seen to range between about 10^8 and 10^{11} ohm-cm, with the majority lying below the critical value of 2×10^{10} ohm-cm.

TABLE I

TYPICAL FIELD VALUES OF FLY-ASH RESISTIVITY

Plant No.	Resistivity
1	5×10^8
2	1×10^8
3	1×10^{10}
4	5×10^9
5	3×10^{10}
6	6×10^{10}

Field resistivity measurements are useful not only for scientific analysis of precipitator operation, but are also of great practical benefit in the diagnosis of precipitator difficulties, particularly where the symptoms indicate that high dust resistivity may be a factor. In agreement with theoretical expectations, the work has definitely demonstrated the close relationship between particle resistivity and precipitator performance and operation.

The effects of high-resistivity ashes are usually manifested by the occurrence of relatively high sparking rates and low corona currents in the precipitator, both of which may adversely affect performance.

Research On Fly-Ash Conductivity

Fly ash is a complex mixture of inorganic compounds similar in characteristics to certain vitreous insulating materials which in the pure state have high electrical resistivities of the order of 10^{14} to 10^{15} ohm-cm.

Our previous discussion has indicated that the conductivity of fly ash for temperatures below about 550° F depends basically on the presence of moisture and of certain chemical impurities in the gas which are adsorbed on the particles.

The influence of varying amounts of these chemical conditioning substances is indicated by the fact that a wide range of fly ash resistivity is encountered in practice, ranging between about 10^6 and 10^{14} ohm-cm for measurements made in the laboratory, and between about 10^8 and 10^{11} ohm-cm for field measurements.

Research on the nature and identity of the chemical substances specifically responsible for conductivity in fly

ash was initiated in our laboratory in 1946. Prior to this time a large amount of laboratory and field information regarding fly-ash conductivity had been accumulated and qualitative explanations for some of the phenomena involved had been advanced.

However, the fundamental question regarding the nature and identity of the active conditioning substance or substances was completely unanswered, as were of course contingent questions regarding the amount of the conditioning substance required and the conditions and factors influencing its presence and generation in boiler gases.

Isolation of Natural Conditioning Agent

Reference to Fig. 6 reveals the rather striking result that the resistivity values measured for the cooling portion of the resistivity-temperature cycle are substantially higher than those obtained for the heating portion.

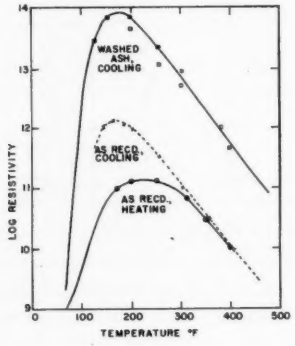


Fig. 6

This result is strong evidence that some volatile substance other than water vapor is profoundly influencing conductivity. Isolation of this natural conditioning substance was one of the major objectives of the research.

If one assumes that the conditioning effect is produced by a volatile and soluble chemical substance adsorbed on the particle surfaces, then it should be possible to remove the conductivity either by heating the fly ash to high temperatures as shown above, or by leaching with water or other liquid solvents.

Experiments were initiated early in the project to determine the effect of leaching fly-ash samples with water. Tests were carried out in which given amounts of fly ash were washed with distilled water and the resistivities of the washed and dried ash then re-determined and compared with the values obtained for the raw ash.

Fig. 6 shows the typical results, the sample in this case having been obtained from a Midwest power plant. Note that the peak value of the resistivity of the raw fly ash is of the order of 10^{12} ohm-cm on the cooling cycle, while the peak value of the washed and dried ash rises to about 10^{14} ohm-cm.

Thus the effect of washing the ash is to raise its resistivity by a factor of approximately 100. The same general result has been confirmed for a wide range of fly-ash samples obtained from many different power plants.

Having established the fact that the conductivity factor or agent is water soluble, the problem was reduced to that of identifying the effective chemical substance which presumably was carried away in solution in the water used to wash the ash.

Chemical analysis of the filtrates obtained from washing the various ashes showed that they were comprised primarily of sulfate and lime, with small quantities of alkali also present. It therefore appeared that the conditioning effect was due either to the presence of the sulfate or the lime, with the former being the most probable because of the previously observed effects of strong heating in destroying the conductivity of the ash.

Heating Causes Loss

At this juncture, experiments were conducted to quantitatively determine the loss of SO_3 which presumably occurred when the ash was strongly heated in an electric oven. The results obtained are shown in Table II and clearly establish the definite loss of SO_3 caused by the heating.

TABLE II

LOSS OF SO_3 FROM FLY ASH PRODUCED BY THE RESISTIVITY MEASUREMENT PROCEDURE

Ash Sample	Percent Dissolved Solids	Percent SO_4
As received	2.82	2.13
After resistivity test	2.33	1.63

Thus the increase in ash resistivity previously noted for the cooling portion of the resistivity-temperature curve can be logically ascribed to the loss of SO_3.

In order to further test the indicated result that the conductivity is due to the adsorption of a water-soluble chemical substance, a sample of a leached ash which had been shown to have a very high resistivity was mixed with the filtrate originally obtained in washing the ash, and the mixture reduced to the dry state in an oven at about 100° C.

A resistivity-temperature test was then run on the dried sample. The results of these tests, given in Table III, are

TABLE III

EFFECT OF RE-COMBINING A WASHED FLY-ASH SAMPLE WITH ITS FILTRATE ON RESTORING THE CONDUCTIVITY

Temperature	Resistivity in Ohm-cm		
	Natural Ash Dried	Washed Ash Dried	Washed Ash plus Filtrate Dried
200° F	2.4×10^{11}	1.9×10^{13}	1.8×10^{12}
250	1.7×10^{11}	6.9×10^{12}	1.7×10^{12}
300	1.0×10^{11}	4.4×10^{12}	1.5×10^{12}

definite evidence that the conductivity of the washed ash is partially restored by the addition of the filtrate.

As a further check on this result, a resistivity test was made on washed ash to which 0.75% of $Ca(OH)_2$ had been added. This produced no measurable effect on the resistivity. An interesting sidelight was the observation that the solid residue left after the evaporation of the filtrate from the washed ash fluoresced under the influence of ultraviolet light. However no definite relation between this fluorescent property and the resistivity of the ash has been established.

Origin and Concentration of the Natural Conditioning Agent in Boiler Gases

Chemical analyses of coals have been made for many years by the Bureau of Mines[6] and other agencies. The cumulative results show that sulfur is present to at least a small degree in all coals. The amount ranges from a small fraction of a percent up to about 5%. Under the high-temperature conditions existing in boiler furnaces, the sulfur is oxidized, mostly to SO_2, and to a small degree to SO_3.

The actual concentrations found in furnace gases are of the order of magnitude of 0.1% for SO_2 and 0.001% for the SO_3. These concentrations in any given case will depend on the sulfur content of the coal burned, and on the furnace design and operating conditions, but the amount of sulfur present would always be far more than adequate to condition the fly ash if sufficient conversion to SO_3 occurred.

Calculation indicates that the absolute amount of SO_3 conversion required for conditioning of the ash usually corresponds to only about 1% of the SO_2 present in the boiler gas.

A rough correlation exists between the sulfur content of a coal and the sulfate content of the corresponding ash. In general, those coals which are high in sulfur will produce an ash high in sulfate, and conversely; but because the correspondence is far from exact, other factors must also be considered.

These other factors include maximum furnace temperature, temperature gradients in the furnace, and the possible presence of catalysts, e.g., iron oxide, for the conversion of SO_2 to SO_3. There is also evidence which indicates that the presence of lime in the ash aids in fixing or binding SO_3 to the ash particles.[7]

But knowledge of these factors is at present incomplete and probably will require much further work before they can be reasonably understood and predicted.

One of the striking and significant conclusions of the research on fly ash conditioning is that the sulfate conditioning substance occurs almost entirely on the particle surfaces. Strong evidence for this is also supplied from some work of Davis[8] carried out in 1938 on the use of fly ash in concrete.

Davis reported the chemical analyses of 18 different fly-ash samples, giving both the total analysis and the analysis of the water-soluble portions. From Davis' results one observes that most of the sulfur content of the ash determined as SO_3 was present in the water-soluble portion; the average of the 18 ashes reported on showed that 86% of the SO_3 was soluble; and in several cases the figure was 90% to 100%.

Thus these results support our conclusion that the bulk of the sulfur in the ash is present on the surfaces of the particles, and has been adsorbed from the SO_3 or H_2SO_4 in the flue gas.

Artificial Conditioning by Sulfuric Acid

The next step in the research was to definitely establish that the injection of small quantities of SO_3 or H_2SO_4 fume directly into the inlet gas stream of a laboratory precipitator would produce a very strong conditioning effect. For this phase of the work, a single 6-inch diameter pipe precipitator was set up.

Provisions were made for heating the inlet air to temperatures as high as 340° F, and a dispersing apparatus was used to feed fly ash into the heated air stream. Acid fume was injected directly into the hot air stream just ahead of the inlet to the test precipitator.

The precipitator was energized with a 60-cycle half-wave voltage. A gas flow of approximately 100 cfm was used, and an inlet ash loading of about 3 grains per cubic foot. No moisture was added to the inlet air during the tests, so that the humidity was that of the atmosphere or about 1% to 2% by volume.

This value may be compared with the 5% to 10% gas humidity for an average fly-ash precipitator installation. Clearly, the lower humidity for the laboratory tests would tend to emphasize the conditioning aspects of the acid.

Preliminary observations were made of precipitator operation and ash resistivity at a temperature of 250° F and with no conditioning of the ash.

Under these circumstances no precipitator sparking was observed, but the corona current rose rapidly to about ten times normal due to the occurrence of high-current back corona which was observed visually in the pipe, and precipitator efficiency dropped to a low value.

This high-current back corona had been predicted from the resistivity measurements made in the laboratory, which for these conditions gave a value of 1.5×10^{13} ohm-cm.

Violent Sparking

Sulfuric acid fume was then fed into the inlet gas stream. The immediate result was violent internal sparking in the precipitator, which is characteristic of the intermediate phase of back corona and which started simultaneously with the acid fume feed and gradually decreased as the fume feed was continued.

The precipitator current also dropped abruptly when the fume was started and then continued to drop at a slower rate. Fig. 7 shows the effect of the acid fume on

the voltage-current characteristics of the laboratory fly-ash precipitator.

Note the great reduction in corona current and the rise in voltage produced by the acid fume. These are the classical effects of conditioning agents in precipitation practice and definitely establish the potency of SO_3 as an effective conditioning agent for fly-ash.

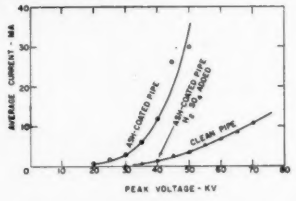


Fig. 7

Systematic tests were next made to determine the conditioning effect of the sulfuric acid fume over a range of operating temperatures. Samples of the ash collected in the laboratory precipitator were analyzed for sulfate content, and measurements were made of the concentration of the acid in the precipitator outlet gas.

These tests proved that, for gas temperatures in the range of at least 150° F to 350° F, the resistivity of the ash is substantially lowered by the injection of small amounts of acid fume. The results also indicated that only a small amount of acid, equal to about 0.4% by weight of the ash used, was required to reduce the resistivity of the ash to 10^{10} ohm-cm or lower.

Increasing the amount of acid beyond this value lowers the resistivity even more. The effect is illustrated in Fig. 8 in which the resistivity is plotted as a function of gas temperature for varying amounts of H_2SO_4 fed into the gas stream.

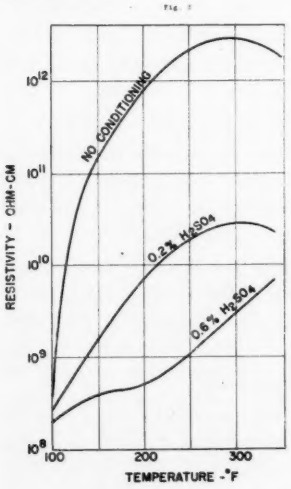


Fig. 8

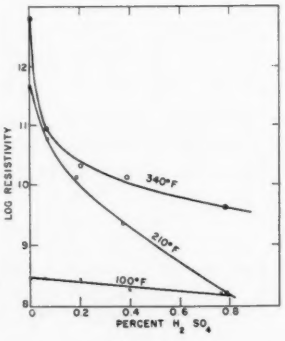


Fig. 9

The percentages of H_2SO_4 indicated on the individual curves are relative to the weight of ash going to the precipitator. Fig. 9 shows the same data plotted in terms of the percent of H_2SO_4 added, with gas temperature as a parameter.

Acid Amounts Vary

The amount of acid deposited on the ash in these experiments which actually is effective in reducing the resistivity is much smaller than the amount of acid introduced into the test precipitator. Several methods were used to determine the amount of acid adsorbed on the dust.

These included colorimetric determination of the SO_4 ion in the leaching water from the ash, pH value of the leaching water, and electrical conductivity of the leaching water. The results of these measurements are given in Table IV.

TABLE IV

AMOUNT OF SO_4 ADSORBED ON CONDITIONED FLY ASH IN LABORATORY TESTS

Pipe Temp. °F	Percent H_2SO_4 Added	Percent H_2SO_4 in Precipitated Ash
280	0	0.0003
"	0.11	0.001
"	0.19	0.005
"	0.41	0.007
"	0.80	0.011

Clearly, only a small fraction of the acid fed to the gas actually appears on the fly-ash particles, and the amount of acid required for conditioning is surprisingly small, being of the order of only about 0.01% or about one part in ten thousand.

These experiments provide conclusive evidence of the strong conditioning effect of sulfuric acid or SO_3 fume on fly ash under actual precipitator conditions.

The classical conditioning effects observed were: (1) The resistivity of the ash was substantially lowered by using only a fraction of a percent of acid; (2) this reduction in resistivity permitted operation of the test precipitator at much higher voltages without back corona or sparking; (3) visual observations showed that the efficiency of the precipitator was greatly increased when the conditioning agent was used.

Search for Other Conditioning Agents

The question naturally arises as to the possible existence of other effective conditioning agents in addition to H_2SO_4 and SO_3, and a number of representative chemicals were tested with this objective in mind. The chemicals tried included:

1. Gases:
   - Ammonia
   - Chlorine
   - Hydrogen chloride
2. Liquids:
   - Hydrochloric acid
   - Ammonium sulfate solution
   - Chlorosulfonic Acid

3. Solids:
   Calcium hydroxide
   Calcium sulfate
   Calcium chloride
   Sodium sulfate
   Ammonium sulfate

The choice of these chemicals for trial was based in part upon previous general experience with conditioning agents on other types of particles. The experimental equipment was similar to that used for the artificial conditioning tests with sulfuric acid.

As would be predicted, the liquid and solid sulfates produced considerable conditioning effect because of the presence of the sulfate radical. However, other chemicals such as ammonia gas, calcium hydroxide, and calcium chloride produced no measurable effect.

Of all of the substances tried in addition to the sulfates, only hydrogen chloride and hydrochloride acid produced any positive effect and even this was relatively small when compared with that produced by sulfuric acid, and indicated that HCl would not be a practical conditioning agent for field application.

Although our search for additional conditioning agents has been by no means exhaustive, it appears reasonably certain that sulfate, the conditioning substance naturally present in fly ash, although not always in adequate amounts, is by far the most effective one available and that there is little probability of finding other agents of greater effectiveness.

Relation of Water-Soluble Content to Conductivity of Fly Ash and Precipitator Performance

The chemical and physical characteristics of fly ash are known to be of great importance in determining the operating efficiency of fly-ash precipitators. The major factors include particle size, particle density, percent combustible, electrical resistivity, water-soluble content of ash, and chemical composition of the water-soluble portion.

Inasmuch as fly ash is a heterogeneous and extremely variable material, depending upon such factors as coal burned, type of furnace, boiler load, and other operating conditions, it is of extreme importance to determine both the physical and chemical characteristics of a wide variety of ashes and to correlate these insofar as possible with precipitator performance.

Analysis of the aqueous extracts of fly ash is carried out as follows. First, a one-or two-gram sample of fly ash is extracted with water in a Soxhlet apparatus. The percent water-soluble, chemical analysis, and pH value of the resulting solution are then determined as previously stated.

Our investigations have shown that the two most prominent constituents in these aqueous extracts are sulfate and calcium oxide. The research has further revealed a close relationship between the sulfate and lime content on the one hand and potential precipitator performance on the other hand.

In general, high water-soluble and sulfate content are correlated with superior precipitator performance, and conversely. This fact is of great fundamental and practical importance, for it provides the necessary key to good electrical operation and therefore to high potential performance. The result has a rational physical explanation because of the demonstrated relationship between the sulfate content and the conductivity of the fly ash.

The correlation between the water-soluble and sulfate content of fly ash and precipitator performance is illustrated by the data in Table V.

TABLE V

RELATION BETWEEN WATER-SOLUBLE AND SULFATE CONTENT OF FLY ASH AND PRECIPITATOR PERFORMANCE

Plant No.	Percent Dissolved Solids	Percent SO_4	Precipitator Performance
1*	6.07	2.93	Normal
2	3.03	.....	Excellent
3	1.95	1.2	
4	1.90	1.2	
5	1.45	0.92	Normal
6	1.40	.....	
7	0.44	0.44	
8	0.43	0.24	Sub-normal
9	0.40	0.37	

*Fly-ash sample taken at outlet of mechanical collector which preceded the electrostatic precipitator in this installation.

These data also indicate the following significant facts: (1) the water-soluble content of fly-ash samples varies from a fraction of a percent up to about 10%, with the average lying in the range of 1½% to 3%; (2) the SO_4 content ranges from a few tenths of 1% up to about 4% or 5%, the average being of the order of 1% to 1½%; (3) the values for the lime content cover approximately the same range as the sulfate; (4) the pH value of the solute varies from about 3 to 12.

Thus we have arrived at the interesting situation whereby the electrical operation of a precipitator, and therefore its performance and efficiency, is to a major extent determined by the chemical composition and water-soluble content of the fly ash. This relationship is by no means an obvious one and could only have been found through basic research.

It may be mentioned that there is good correlation between the pH value and the relative percentages of SO_4 and CaO. Those ashes which have a stoichiometric excess of lime, calculated as $CaSO_4$, are basic in character, and conversely for those which have an excess of sulfate. Moreover, it should be noted that there is no apparent relationship between the pH value of a solute and the precipitability of a fly ash.

There is considerable evidence that the soluble portion of fly ash is associated predominantly with the finer particles. This is indicated, for example, in Table V by the

sample from Plant No. 1, which was obtained on an installation comprising a mechanical collector followed by a precipitator.

The amount of dissolved solids for the inlet ash to the mechanical collector is 3.03%, and 68% of the particles were in the 0-10 micron range. On the other hand, the dissolved solids in the ash at the mechanical collector outlet rose to 6.07%, and 99% of the particles were in the 0-10 micron range. Chemical analyses made on particle-size fractions of fly-ash samples also bear out this general result.

Field Tests On Conditioning Action of SO_3

The discovery and proof of SO_3 as the conditioning agent naturally present to a greater or lesser degree in all fly ashes, and the further proof of its potent fly-ash conditioning properties in laboratory precipitator experiments, logically led to field tests using SO_3 or H_2SO_4 as the conditioning agent.

A quantitative basis for field tests had been established by the laboratory result that the amount of H_2SO_4 required for effective conditioning is of the order of 0.4% by weight of the fly ash treated.

This figure should represent the maximum quantity of H_2SO_4 required because of the fact that fly ash in the field always contains at least some sulfate and also because the time for adsorption in a field precipitator would be several times greater than the fraction of a second which existed for the corresponding laboratory tests.

Field conditioning tests were conducted on two separate precipitator installations, both of which were operating at somewhat below expected performance figures, and chemical anlysis of fly-ash samples collected from these units had indicated that they were deficient in sulfate content.

In the first test installation, SO_3 was produced by catalytic conversion of SO_2, while in the second installation SO_3 was vaporized from Sulfan, a commercial product of stabilized SO_3 in liquid form.

Equipment Described

It will suffice to describe the tests on the first installation. The equipment consisted of a catalytic converter for producing SO_3 from SO_2, an electric heater to preheat the air entering the converter, and heat-insulated piping to lead the SO_3 vapor to the inlet ducts of the precipitator.

The SO_3 vapor was fed into the inlet duct by means of a series of nozzles specially distributed across the flue so as to provide approximately uniform mixing with the boiler gas.

As a matter of convenience and simplicity, bottled SO_2 was used to feed the converter. Converter operation for most of the tests was at an air-flow rate of about 60 cfm and an SO_2 rate of about 2 cfm.

Precipitator efficiency tests were made by the standard ASME method and runs of one-hour duration were used in all cases. However, before each test, the SO_3 vapor was fed into the precipitator for a period of several hours to ensure stabilization of the conditioning effect.

In the set-up used, conditioning could be provided in either unit of a two-unit precipitator. This enabled direct and simultaneous comparisons to be made on the results obtained with conditioned and non-conditioned ash, using either of the two units for the conditioning comparison.

Before each test the rectifier sets were adjusted to provide optimum electrical conditions, monitored by means of high-voltage resistance dividers and oscilloscopes directly connected to the high-voltage cables energizing the precipitator units. Measurements of the ash resistivities were made by means of the field point-plane resistivity equipment previously described.

The results of the field tests are summarized in Table VI together with the pertinent test conditions. Values of resistivity and precipitator performance factor w* are in each case based on the average of 5 to 10 independent tests taken over a period of about 6 weeks.

TABLE VI

RESULTS OF FIELD TESTS ON CONDITIONING OF FLY ASH WITH SO_3

Conditioning	Fly-Ash Resistivity Measured in Flue	Pptr. Performance Factor—w
No	6×10^{10} ohm-cm	0.29
Yes	3×10^{9}	0.42

Test Conditions:

Fly ash concentration at precipitator inlet	Approx. 3 grains/cu ft
Gas temperature	350° F
Precipitator gas flow	230,000 cfm/pptr unit (120% of rated value)
Amount of SO_3 used	Approx. 2 cfm
Gas velocity in precipitator	12 ft/sec

The important conclusions are: (1) the SO_3 conditioning reduced the resistivity of the ash by a factor of approximately 10, and (2) increased the precipitator performance factor w by nearly 50%.

Thus the positive results predicted from the laboratory research were in fact achieved in the full-scale field conditioning trial, both in the reduction in fly-ash resistivity and in the resultant large improvement in precipitator performance.

Conclusion

One of the primary objectives of the paper is to illustrate the role of fundamental research in understanding and solving the typical problems which occur in the control of air pollution from industrial sources.

Most of the early work in this field was of necessity

*The precipitator performance factor w, which is mathematically related to collection efficiency, is a direct measure of the rate of particle collection, and therefore of precipitator performance. (See reference 2).

empirical, but such an approach is wholly inadequate to cope with the exacting demands imposed by modern industrial and community requirements, and is increasingly being supplanted by the scientific method.

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Application of Bag Filters to Metallurgical Fumes

By Charles D. Schmidt
Whiting Corporation, Harvey, Illinois

The development of the Whiting high-temperature bag type suppressor was brought about by the 1950 change in regulations of the Los Angeles Air Pollution Control District. Early in 1949 the General Metals Corporation of Los Angeles ordered two cupolas equipped with standard spark and fly ash suppressors. We had guaranteed this equipment to comply with the regulations of the Los Angeles Air Pollution Control District.

After the placing of this order, but before installation of this equipment, the regulations of the District were drastically revised. The allowable emissions of particulate matter were reduced from 50 lb. per hour to less than 10 lb. per hour based on the process weight of the materials charged into these cupolas. After the wet type spark and fly ash suppressors were installed, tests were run and it was evident this type of suppressor would not meet the new code.

Whiting was faced with the problem of either losing all of its foundry customers in Los Angeles County or developing a suppressor that would meet the code and still be in the foundry price range. A long period of testing and modifying equipment and then more testing and more modifying followed—all with discouraging results.

After many months of labor we were firmly convinced that all economically feasible methods of collecting the fine metallurgical fume from cupolas with wet scrubbers had been explored and the code could not be met.

Equipment Described

The method of testing and the equipment used is described in detail in the Bureau of Mines Information Circular 7627 "Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County, California." Briefly, this method is best described as sampling a continuous sample.

The primary sampling was accomplished with an 18″ square hood, located in the stack at the point where conditions most nearly approach average stack velocities, connected to a 12″ diameter duct. The secondary sampling in the 12″ duct was accomplished with a glass sampling tube, followed by one wet and three dry Greenberg Smith impingers and two Whatman thimbles, in series.

The second Whatman thimble was used as a check only. The testing procedure followed was prescribed by the Industrial Air Control Associates, Technical Sub-Committee Gray-Iron-Foundry Smog Committee Report: December 16, 1948.

During this testing period it was noted with considerable interest that the first thimble in the train of sampling equipment always collected all of the particles that escaped from the series of impingers. The second thimble was not necessary from a collection standpoint.

When it became evident that the wet scrubber and its various modifications would not meet the code, our engineers began to investigate the possibilities of adapting a bag filter type collector for use with cupola.

Small Scale Beginning

Experiments with the filter were started first on a laboratory scale and when it had been determined that collection efficiencies would exceed the efficiencies required by the Los Angeles Code, a pilot model that could operate in the field was built. This pilot model was installed at the General Metals Corporation in Los Angeles.

This pilot unit was a pressured type bag suppressor, i.e. operated from the discharge side of the exhauster. It was fitted for a maximum of five bags, each 12″ in diameter and 14′ 4″ long, or 45 sq. ft. of cloth area per bag, or a total of 225 sq. ft. of cloth area if all five bags were in use.

Gases were withdrawn from the cupola stack thru a sampling hood placed approximately at the point of average stack velocity. The open area of the hood was 64 sq. inches. The gases were led from the hood to a 5 H.P. mill type exhauster, then thru a 6″ dia. duct to the bag type suppressor.

The result obtained from field testing this pilot model convinced us that we could meet the code with this type of equipment. Further testing of different bag fabrics, types of shaking, and various air-to-cloth ratios followed.

Full-sized Suppressor Designed

The information gained from these tests was used as a basis for designing a full size suppressor to handle the emissions from a No. 3½ closed top cupola, 51″ shell diameter, lined to 37″ inside diameter. This full size unit was the end result of more than a year and a half of research and development and the expenditure of nearly $100,000.00.

This unit was the first to pass the Los Angeles Code. On January 12, 1951 the first unrestricted official permit for a cupola suppressor was issued to General Metals Corporation by the Los Angeles Air Pollution Control District. The official test of this unit showed a loss of 0.21 lb. of particulate matter per hour as compared to an allowable loss of 10.1 per hour.

Larson Quoted

Mr. Gordon Larson, director of the Los Angeles Air Pollution Control District, after seeing the test results and the suppressor in operation, has stated: "Nowhere in the world, as far as we know, has the emission of cupola

dust and fumes been reduced to the level accomplished by this new equipment. The first successful system to be applied to iron melting cupolas, this suppressor is regarded as a milestone in the progress of smog eradication in Southern California."

This first unit utilized the existing wet collectors on top of the cupola stacks as water spray coolers to bring the exhaust stack gases down to 500 Deg. F., the preferred operating temperature for these bags. On the following twenty some units these hot exhaust gases are cooled by the use of automatically controlled water sprays in a conditioning chamber at ground level.

Final Results

The final results of this unit have been the complete elimination of all visible smoke and fume and the collection of large quantities of extremely fine powdery substance in the hoppers below the bags. A large portion of this collected material is too fine to settle out when emitted to the atmosphere and formerly constituted a part of the smog blanket over Los Angeles.

A very good summary of the report submitted by the Gray-Iron-Foundry Smog Committee can be found in table 5—Testing Cupola Operations of the Bureau of Mines Information Circular 7627. This summary shows the variation in emissions that can be expected in cupola operation.

This first unit has now been in daily operation since December, 1951, a little over a year and four months, for an average of eight hours per day, five days a week.

Maintenance Negligible

Other foundries using this type of collector report maintenance, exclusive of bags, negligible. The bags in use have not worn out to date, and we are unable to state what the expected bag life will be, and consequently what the maintenance of the bags will be.

The average cost per CFM @ 500 Deg. F is $1.06. This cost includes all collection equipment and necessary controls and accessories but is exclusive of duct work or erection costs.

At present there are twenty of these units in operation in Los Angeles County, all used in conjunction with cupolas. These units range in capacity from 10,800 CFM to 35,000 CFM and all have received permits to operate.

The closed top cupola, a necessity if all exhaust gases are to be led to a suppressor, with open charging doors, presents an explosive problem during certain periods of the melting cycle due to the carbon monoxide content of these exhaust gases. To insure burning of the carbon monoxide gases, gas burners are placed at the charging door and a continuous flame is maintained during the cupola operating cycle.

The placing of gas burners at the charging door level allows the upper portion of the cupola stack to be used as a combustion chamber and the gas burner flame is the ignition flame present at the point where the elements necessary for combustion are present.

The following is a direct quotation from the Bureau of Mines Information Circular 7627, page 42, concerning other contaminants in cupola emissions: "Zinc and lead in the particulate matter were low enough to offer no significant pollution. The same was true with respect to volatile and condensable oils and tars and to gaseous sulfur compounds.

"Sulfur content of the particulate matter in the form of soluble sulfates, on the other hand, was important from the standpoint of design of remedial equipment."

We have encountered no trouble to date in our conditioning chamber where water sprays are used for exhaust gas cooling. There is no recirculation of water in this system; however, any water which is not evaporated is drained to a sewer.

We are proud of what has been accomplished with our bag type suppressor as related to cupolas. We also believe that many types of industry can apply this type of equipment to troublesome emissions so that clean air in an industrial area is not just a dream but an actual working condition.

If authors wish to have reprints of the papers published in this issue, printing can be arranged by filing requests with Headquarters, which will advise as to cost for the number of reprints desired.

Engineering and Economic Approach to Foundry Dust Collection

By Mack Gordon, *President*
Aerodyne Development Corporation, Cleveland, Ohio

The dust collection problem in a foundry resolves itself chiefly around the problems connected with industrial hygiene, economical recovery of valuable materials, and general cleanliness. The chief sources of dust generation are the foundry shake-outs, sand handling systems, electric furnaces, cupolas, grinding operations and wood working and pattern shops.

The problem of collecting dust from the above mentioned sources not only entails a collection problem but is concerned with a high loss of heat in most localities. It is very common to find foundries which are air bound due to the high rate of ventilation and the lack of make-up air. Airbound foundries frequently find that equipment dependent on air cannot deliver at rated capacities due to partial vacuum. This high loss when used in northern climates can be quite expensive.

The problem of collecting dust in the foundry cannot be overgeneralized as different geographic locations have different regulations pertaining to dust omission and in addition, techniques involved making castings require different types of equipment and many foundries producing the same type of casting do so by slightly different methods.

It is not uncommon to find similar pieces of equipment operated in different manners so that dust problems are not similar to the manufacturer of dust collector equipment. Two examples of this are difference in operation of the cupolas resulting in differences in dust emission and stack temperatures.

Another example is the differences in operation of shake-outs. Shake-out dust from one foundry having a high concentration of core oil and a resultant fume which is both oily and dusty; and another foundry using the same type shake-out having very little oil in the exhaust gas and the dust consisting principally of sand and bentonite.

These examples are mentioned in order to emphasize the fact that it is unwise and impossible to make general statements as they can easily be disproved. The Aerodyne Development Corporation has principally done experimental and production work on grinding applications, shake-outs, sand preparation, cupolas and wood working. These will be dealt with in order.

Grinding Operations

Dry grinding has received the principal attention due to the fact that the dust problem in this form of grinding is the most acute. It is obviously of importance to retain the air in which the dust is conveyed and collected and return it to the building proper.

It is possible to do this with the use of a high efficiency mechanical collector. The returned air can be cleaned so that there are less than three million particles per cubic foot. This is well within the code limitations and is cleaner than the air in most foundries.

It has been found sometimes necessary to use a precleaner in conjunction with the dust collector in order to accomplish this. One interesting feature has been the return of the cleaned air back into the foundry using an Aerodyne cone without casing, under pressure so that the unit acts both as a collector and an air diffuser.

Shake-Outs

Shake-outs have been for many years an annoying source of dust in the foundry and constitute two main problems. First of all, there is the problem of collecting the dust by proper hoods, ducts or other means so that the dust may properly be conveyed into a collector.

The second problem is that of collection of the conveyed dust at the collector. The problem of collecting the dust at the shake-out is a complex problem and an individual problem. Each foundry has its own method of introducing castings to the shake-outs, its own structural support of the shake-outs, etc., and in most cases, the hood requires individual attention and design.

It is possible frequently to re-use some of the clean gases and re-introduce them over the shake-out area so that the total gas withdrawn from the foundry can be considerably reduced, thereby reducing the amount of make-up air. This type system calls for careful consideration and good engineering.

It is important to remove no more of the fine dust such as silica, bentonite and sea coal from the molding sand than is necessary. If considerable quantities of fines are continually removed, the molding mixture becomes coarser and coarser and the castings eventually will have poor finish.

Our work has been connected with developing the means of returning the fines to the molding mixture so that this condition can be avoided. Through the use of a dry mechanical collector it has been possible to recover 92% of the fine bentonite, sea coal, silica and return this dust to the molding mixture so that long periods of time elapse before the molding mixture becomes degraded.

One large foundry has estimated that the dust collecting system will pay for itself in three to six months due to

this feature alone. It is of interest to note in passing, that the collected dust contains practically no iron.

Many foundries have a different material handling problem in moving collected dust to a final point of disposal. The final point of disposal can be either a bin or a location in a handling system. The Aerodyne equipment has been able to collect and convey dust so that the labor of handling has been eliminated.

Sand Preparation

Sand preparation requires ventilating hoods and take-offs from such diverse pieces of equipment as mullers, conveyors, revivifiers, vibrating feeders and elevators. The problem once again consists of properly designing a collecting system and conveying the dust to a collector.

It has been found possible to collect this dust with high efficiency with a mechanical collector and to return the collected dust back into the system. This reduces the loss of valuable sea coal and bentonite. It is possible to engineer a rather complex system and eliminate all sludge tanks, man handling, thus greatly reduce maintenance.

Cupolas

The problem of collecting dust from the cupola is a complex problem related principally to plant location, local ordinances, and atmospheric conditions. By way of example, the Los Angeles code is sufficiently rigid that the latest information would indicate the only allowable pieces of equipment to the authorities in Los Angeles County are bag collectors and electrostatic collectors.

The stringency of these regulations is caused by a local atmospheric condition. In other parts of the country, wet scrubbers and mechanical collectors are in common use.

By far the widest used piece of equipment is the wet scrubber. Our experimentation has been conducted on using a dry mechanical collector. Chief advantages of this piece of equipment being that it is rather simple and requires little maintenance. Our efforts have been directed to finding a practical means of reducing high gas temperatures commonly found in cupola stacks and finding some use or market for the collected dust.

The first problem has been solved in a fairly satisfactory manner by introducing large amounts of excess air and reducing the temperature before entering the dust collector to no more than 1000° F. Satisfactory equipment can be designed for 1000° quite readily.

The collected dust in several installations has a high iron content and it has been possible to sell this dust for re-use in the blast furnaces. It is interesting to note that there is a possible use for this dust as a source of trace minerals in agriculture.

It is possible to design a high efficiency mechanical collector which will collect as high as 92% of the dust emitted by a cupola. Cupolas are in use which recover heat from the cupola exhaust and exchange this heat for the cupola air blast. This equipment is expensive and rather complex.

A market for this equipment exists with large production foundries. The small foundry cannot economically use this system. It is, however, entirely possible to produce a combination air heater and dust collector in which the heat exchanger is used to preheat make-up air for the foundry.

Woodworking

It is relatively easy to collect wood refuse and return the air to the foundry. This is accomplished by using a drop-out box for large wood chips and an Aerodyne cone to collect the very fine material.

The use of outside air for foundry ventilation can often be utilized for a dual purpose. Air curtains can use outside air and pouring stations can be cooled or ventilated by this means.

Foundry dust collection should always be considered in relation to its economic aspects as well as to proper dust collection.

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Internal Flow Problems in Mechanical Centrifugal Dust Collectors

By E. H. R. Pegg, *Vice President*
and
D. W. Gibbs, *Engineering Department*
The Aerotec Corporation, Greenwich, Connecticut

The principle of dust collection by centrifugal force has been used for many years. The general type of collector based on this principle and most widely used for fly ash collection consists of a multiplicity of collecting tubes operating in parallel.

In each tube there are openings to three common spaces. These are the gas inlet, gas outlet and dust discharge sections. In operation, the dirty inlet gas is induced to spin by the shape of one or more inlet openings, and the suspended dust, being heavier than the gas, tends to be thrown to the outer portion of the spin by centrifugal force. The gas leaves the tube from the relatively clean central area, while the dust is carried to the discharge opening by the direction of the spin.

Considering only the individual tube the optimum dust collection is obtained through the creation and most advantageous utilization of maximum centrifugal forces. The shape and proportions of the tubes are very important, and most available designs are the result of considerable experimental work by the various manufacturers.

Operational factors influencing collection are size, shape and weight of the dust particles and the pressure drop or flow rate at which the collector operates. With other things being equal, a tube of small diameter will generally produce higher collection efficiencies than a larger tube of the same proportions in all parts, since the small diameter causes higher centrifugal force. This fact, among others, has led to several designs consisting of large numbers of tubes with diameters in the range of three to ten inches.

It has long been recognized by those familiar with multiple tube centrifugal collectors that factors other than the design of the individual tubes are of paramount importance to proper operation, and in the past some installations have obtained efficiencies very much lower than would be obtained from independent tubes. This has been true of most designs of this general type and would probably be found true of all if complete information could be assembled.

"Recirculation" to Blame

Barring any more obvious sources of trouble the factor usually responsible for poor performance is so-called "recirculation." This refers to a secondary gas flow between tubes through the dust discharge section, and is caused by unbalance in the main flow through the tubes. The term recirculation, while not exactly descriptive of the conditions existing, has become established through usage and lack of a better term.

This flow through the dust discharge section leaves some tubes in the same direction as the dust discharge and enters others in the opposite direction. Flow in the same direction as the dust discharge is of little concern.

However, flow opposite to the dust discharge upsets the normal action in the tube and inhibits or prevents the discharge of dust as well as re-entraining dust already collected by other tubes. Consequently, serious dust losses occur if the secondary flow is sufficiently large. A more commonly recognized similar condition exists if the hopper is under negative pressure and leakage into the hopper occurs.

Unfortunately, recirculation is not always apparent because there is little or no manifestation that it exists except indirectly through the collection efficiency, which can only be determined through difficult tests. Also, even if recirculation is suspected it is very difficult to detect, let alone measure quantitively or analyze its sources in existing collectors.

Recirculation may be caused by several possible sources of unbalance. For example, it can readily be seen that physical variations in the tubes, such as pluggage, non-uniformity occurring in manufacture, or non-uniformity due to wear, will unbalance the flow by creating characteristics different in some tubes than in others.

Also, non-uniformity of the gas distribution, either in the inlet or outlet sections, is a source of dynamic unbalance. This may be due to the arrangement of the connecting ducts or various obstructions in the gas stream such as vanes, baffles or dampers near the collector. It may also be due to sources within the collector itself because of the practical impossibilities of obtaining perfect manifolding.

A Necessary Compromise

Under the usual circumstances any installation of this type must necessarily be a compromise with ideal conditions. As a result, some installations of a particular design may be very satisfactory while others are not.

Up to this point, this paper has dealt in generalities to help introduce our more specific investigations and explain why the underlying problems are not limited to the one particular collector design which will be discussed in detail.

Our direct investigations have, of course, been confined to our own collector designs and most specifically to the

one designated as Des. 3 RAS, which is in widespread use for fly ash collection. This consists of three-inch diameter tubes arranged in banks.

These tubes collect dust with very high efficiency because of their small diameter and design. They incorporate a cone on the dust discharge opening which tends to stabilize the internal flow and permits satisfactory operation with moderate degrees of unbalance. Also, the tubes have a very high degree of uniformity since they are permanent mold castings. (See Figure No. 1 showing single tube.)

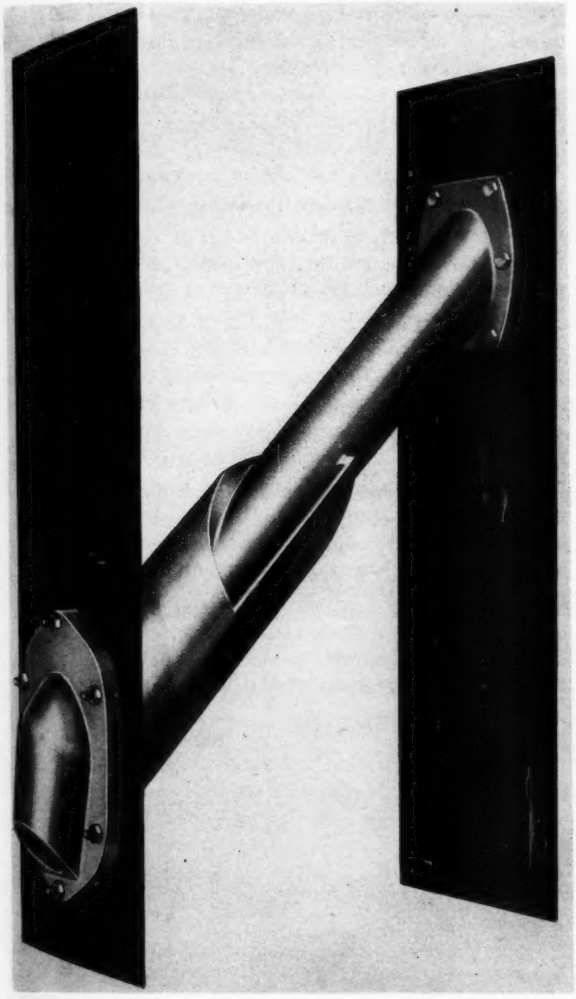


Fig. 1.

Many arrangements are possible and collectors can be built with these tubes so that the inlet and outlet can be at the side, top or bottom to suit capacity and layout requirements. However, the so-called straight-through arrangement with inlet and outlet on opposite sides is by far the most extensively used. (See Figure No. 2 which shows a typical straight-through unit.)

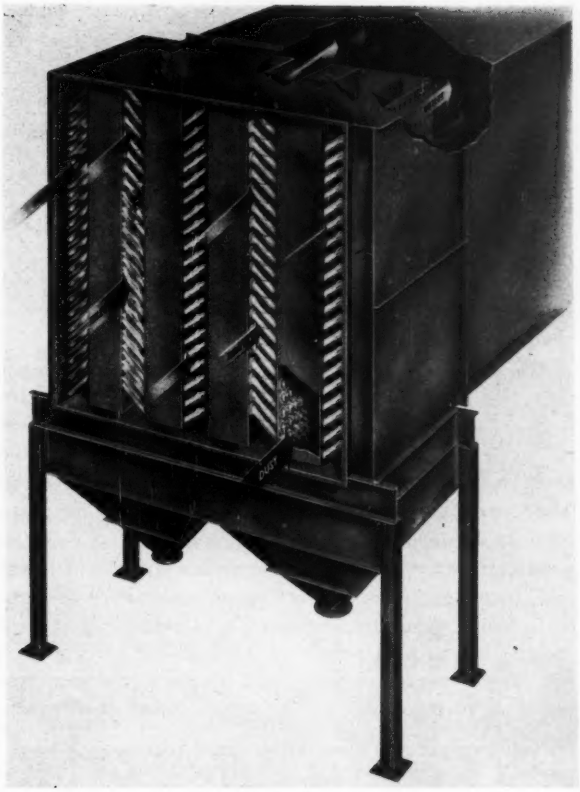


Fig. 2.

Collectors of this design have been installed in a large number of power plants starting over six years ago and many have been tested both by ourselves and our customers. The results from a majority of the installations tested have proven the design to be highly acceptable from an efficiency standpoint.

However, poor results have also been obtained at some installations. These cases of poor efficiency, while being the cause of much concern and considerable investigation, must be considered as individual problems as they are attributable to extreme conditions at the particular installations.

Once recognized and understood, such extreme conditions are usually susceptible to corrective measures.

Tube Erosion

Important as this may be, another more general and pressing problem has been the fact that after accumulating operating time, some of these installations have experienced tube erosion much more severe than was ever anticipated from early tests in the development of the design or from experience with the first field installations.

It has become apparent that major differences in erosion have been due to differences in operating conditions and types of fuel from one installation to another. The most striking example in this regard is found in the first collector installed with this basic design of tubes.

A recent inspection has shown this unit to be in excellent condition after six years of operation, and from the observations made it can be expected to remain in good condition for many years to come.

One possible way to reduce erosion is the substitution of more erosive-resistant materials where it can be done by practical means. This has been the subject of much of our investigation, both in the laboratory and in the field. The investigations more pertinent to this paper are directed at recognizing and overcoming a principal under lying cause of erosion and at the same time improving the collector performance.

Through the course of internal inspections of many units, definite and recurring patterns were noted in the dust deposits and tube erosion. These observations alone did not constitute much concrete evidence, but they did make it possible to formulate extensive theories about what was taking place.

One fundamental theory was that much of the erosion encountered was due to inherent recirculation, which was not great enough to seriously impair collection efficiency. No reliable means to investigate and substantiate these theories in the field presented itself in the early stages, and such attempts as were made to make field measurements of recirculation led to results which were questionable and difficult to interpret.

One of the problems was that the pressure differentials desired to be measured were smaller than the usual variations and fluctuations existing. Also, it was next to impossible in a complete collector to isolate and study separately the various causes and effects of recirculation.

Another complicating factor was that overfilling of hoppers sometimes occurred with little or no external indication and produced effects very similar to those suspected from recirculation, since both conditions prevent the normal discharge of dust from the tubes. Through the use of a hopper level alarm, which we developed, we are now in a position to minimize this latter problem.

Tests Conducted

To obtain more fundamental and reliable information, several models have been built, and various tests have been conducted in our laboratory. These have made it possible to isolate several causes and effects of recirculation and study them carefully in relation to the various theories which have been formulated. Some of these models have furnished basic knowledge of general interest.

One such model consisted of a single Design 3 RAS Tube set up so that flow into the dust discharge opening of the tube as exists with recirculation could be produced and controlled. The model was equipped with a glass window, so that the internal action of dust in the tube could be observed by means of a flashlight without obstructing the flow. The tube was arranged so that dust could be fed into its inlets in the normal manner. (See Figure No. 3 showing this set-up.)

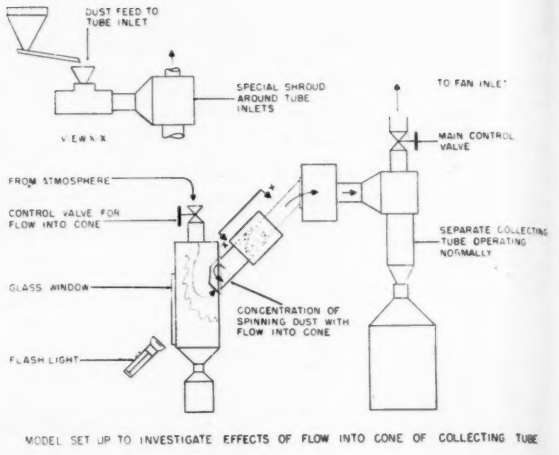

DUST FEED TO TUBE INLET
SPECIAL SHROUD AROUND TUBE INLETS
VIEW X-X
TO FAN INLET
MAIN CONTROL VALVE
FROM ATMOSPHERE
CONTROL VALVE FOR FLOW INTO CONE
SEPARATE COLLECTING TUBE OPERATING NORMALLY
GLASS WINDOW
CONCENTRATION OF SPINNING DUST WITH FLOW INTO CONE
FLASH LIGHT
MODEL SET UP TO INVESTIGATE EFFECTS OF FLOW INTO CONE OF COLLECTING TUBE

Fig. 3.

It was found that the use of a typical fly ash from pulverized coal so obscured visibility that little of value could be seen. However, use of a coarser fly ash from a stoker-fired boiler permitted adequate visibility. It was seen that with no flow into the dust discharge opening, or cone, of the tube the dust discharged rapidly and did not concentrate unduly inside the tube.

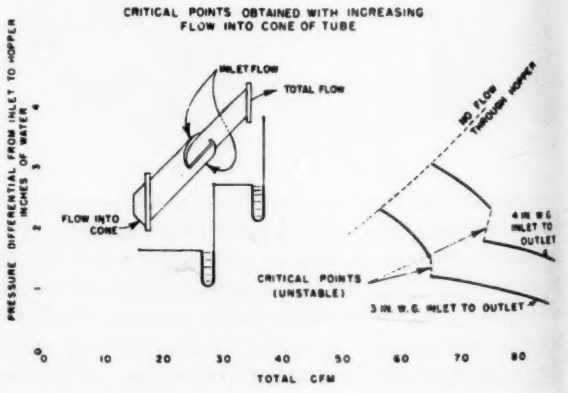
As the flow into the cone was started and increased in steps, the discharge of dust was seen to be inhibited, and a critical point was reached at which a marked change occurred. Beyond this point, very little dust was discharged to the hopper, but instead a heavy concentration of spinning dust formed inside the tube. It was possible to make this concentration of spinning dust appear or disappear at will by starting and stopping the flow into the cone.

With the flow into the cone maintained above the critical point, the concentration of dust would continue to spin indefinitely even after stopping the dust feed.

Measurements Taken

To study the inter-relationship of the flows, pressure measurements were taken of the inlet to hopper differ-

Curve 1.



ential at various degrees of flow into the cone. The inlet-to-outlet differential was adjusted to a constant value for each set of readings and the resulting total flow was measured.

These measurements confirmed that a critical point existed as a gradual increase of the flow into the cone caused a sudden change in the gage readings. (See Curve No. 1 obtained from these readings.) A likely explanation of this critical point is that a certain degree of flow normally exists in the cone.

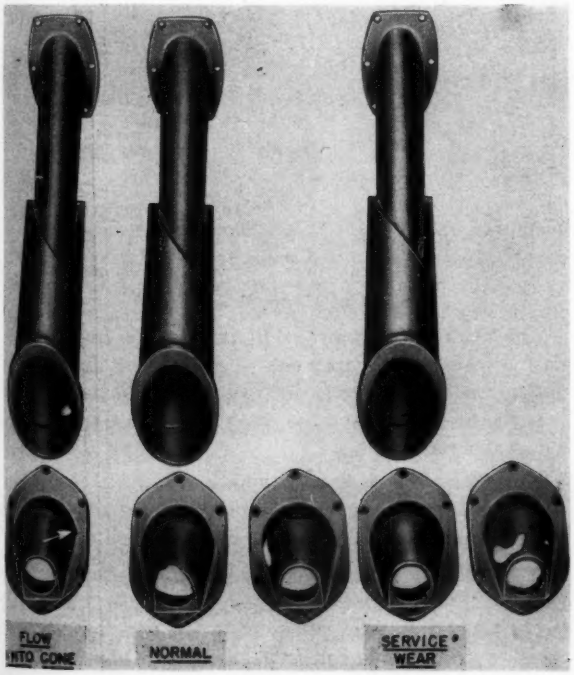
This simultaneously enters and leaves the cone in different locations due to pressure differences from the center to outer portion of the vortex. Under normal operation the flow in both directions balances. However, as the inward flow increases, the outward flow decreases, and at the point where the outward flow ceases altogether, an abrupt change takes place.

Since the condition with a concentration of spinning dust is obviously a source of excessive erosion, a test for this effect was carried out in this same set-up. Unfortunately, such erosion testing consumes enormous time periods, and while it would be desirable to run several such tests under differing conditions, this has not been practical.

Comparative erosion data now available and pertinent to this paper is from one tube which was eroded through in this set-up under one condition of flow into its cone, and another identical tube operated normally at the same inlet to outlet pressure drop and with conditions the same otherwise.

This latter test is still continuing but sufficient data has been obtained to show that, per pound of dust handled, the tube with flow into its cone wore at a rate 4.2 times that of the tube operated normally.

Fig. 4.



This figure is not considered representative of the ratio of service life under the two conditions, because the flow into the cone for the test was clean, while in service this flow would be heavily laden with dust re-entrained from the dust compartment.

This in effect would cause a tube with flow into its cone to handle much greater amounts of dust than a normally operating tube. Consequently, to be representative of service conditions the ratio of 4.2 to 1 should be adjusted upwards by a large but indeterminate amount depending upon conditions.

The wear pattern produced in this test permits worthwhile comparisons with the wear pattern from a previous test without flow into the cone under similar but slightly different operating conditions and with wear patterns encountered in actual service. (See Figure No. 4 showing these patterns.)

Location of Wear

The significant difference is in the location of wear with respect to the discharge edge of the cone. With flow into the cone very little erosion took place at or near this edge, while through-metal erosion occurred near the transition from the main cylinder to the cone.

On the other hand, without this flow the edge of the cone was eroded away completely in one spot with no failure elsewhere. While several variations of wear patterns have occurred in service, the most frequently found pattern has consisted of severe wear at the transition from the main cylinder to the cone with only incidental wear near the discharge edge.

This shows that, in general, the wear pattern predominantly found in service closely approximates that of the tube with flow into its cone and differs from that of the tube without this flow.

As previously mentioned, the arrangement of our collectors most commonly used is the so-called "straight through" arrangement with gas inlet and outlet on opposite sides. There was ample reason to believe that any inherent recirculation in this arrangement was minor, both because the design velocities had been kept low, as had been dictated by past experience, and because of a large number of satisfactory efficiency tests which had been run on completed installations. However, observations and theories indicated that some minor inherent recirculation did exist from front to rear.

In this regard the wear experienced in this arrangement has invariably been confined to, or found worse in, the rear of the tube banks where the recirculation was suspected to be entering the cones of the tubes. Also some differences in the pattern of erosion have been noted from top to bottom and in alternately positioned banks. (See Figure No. 5 showing typical patterns.)

A laboratory model was built to permit investigation of this arrangement. To keep the model within such pro-

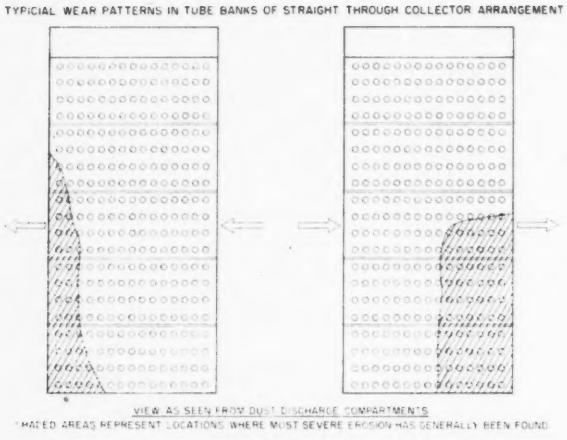

TYPICAL WEAR PATTERNS IN TUBE BANKS OF STRAIGHT THROUGH COLLECTOR ARRANGEMENT
VIEW AS SEEN FROM DUST DISCHARGE COMPARTMENTS
SHADED AREAS REPRESENT LOCATIONS WHERE MOST SEVERE EROSION HAS GENERALLY BEEN FOUND

Fig. 5.

portions that adequate measurements and proposed modifications would be practical, a single row of 15 tubes, as exists in the usual installation, was selected as a starting point. The model was dimensioned with the flow areas the same size as those normally serving a single row of tubes, so that the velocities would be representative.

In designing the model, emphasis was placed on adaptability, so that extensive modifications would later be possible. A lucite panel formed one entire side of the dust discharge compartment to permit internal observations. An orifice, damper, ducts and fan were adapted to form a complete system in which the flow could be controlled as desired. (See Figure No. 6 showing this model.)

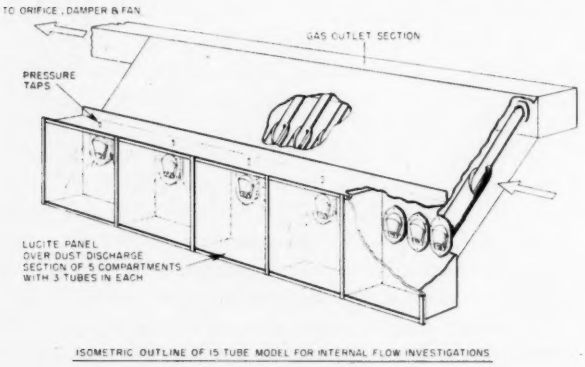

TO ORIFICE, DAMPER & FAN
GAS OUTLET SECTION
PRESSURE TAPS
LUCITE PANEL OVER DUST DISCHARGE SECTION OF 5 COMPARTMENTS WITH 3 TUBES IN EACH
ISOMETRIC OUTLINE OF 15 TUBE MODEL FOR INTERNAL FLOW INVESTIGATIONS

Fig. 6.

Determine Best Approach

Early experiments were observational to determine the best approach for more detailed investigations. It was found that little could be directly observed which would produce much reliable data. However, there were some slight but definite indications of recirculation from front to rear in line with theoretical considerations.

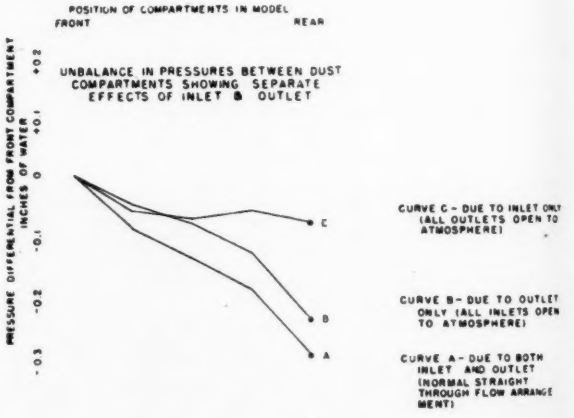
The indications were not sufficiently quantitative for reliable investigation of causes and possible corrective measures. As a better source of data, the dust discharge section was divided into five compartments, so that pressure differentials between them could be measured.

This would not measure recirculation directly as all recirculation was confined to the compartments. It would, however, give an index of recirculation by direct measurement of the unbalance in forces transmitted to the dust discharge compartments.

For simplicity all pressure figures given, relating to this model, will be those obtained at a standardized flow rate, which produced 1.5″ w.g. pressure drop in the orifice. This rate produced overall pressure drop through the model in the range of the usual design conditions.

In the model, as set up, it was seen that a differential from the front to the rear dust discharge compartment of .30″ w.g. resulted. Previous theories indicated that the principal cause was unbalance in the outlet, while unbalancing tendencies in the inlet were largely self-compensating.

To isolate the causes, the inlets of all tubes were first opened to atmospheric pressure, and thus balanced, leaving the outlet condition as the only possible source of unbalance. Then, necessary changes in arrangement were made so that the outlets of all tubes could be similarly opened to atmospheric pressure while the inlet was returned to normal. (See Curve No. 2 showing differentials due to inlet, outlet and both.)


POSITION OF COMPARTMENTS IN MODEL
FRONT
REAR
UNBALANCE IN PRESSURES BETWEEN DUST COMPARTMENTS SHOWING SEPARATE EFFECTS OF INLET & OUTLET
PRESSURE DIFFERENTIAL FROM FRONT COMPARTMENT INCHES OF WATER
+0.2
+0.1
0
-0.1
-0.2
-0.3
C
B
A
CURVE C - DUE TO INLET ONLY (ALL OUTLETS OPEN TO ATMOSPHERE)
CURVE B - DUE TO OUTLET ONLY (ALL INLETS OPEN TO ATMOSPHERE)
CURVE A - DUE TO BOTH INLET AND OUTLET (NORMAL STRAIGHT THROUGH FLOW ARRANGEMENT)

Curve 2.

Unbalance Proved

The results were that the differentials from front to rear dust discharge compartments were .24″ w.g. due to the outlet, and only .08″ w.g. due to the inlet. This confirmed that the principal effect was due to unbalance in the outlet, as theorized.

Following these determinations, an exhaustive series of tests was begun to investigate other effects and develop corrective measures. These tests are much too detailed to report at length, and only a few more important findings will be covered here.

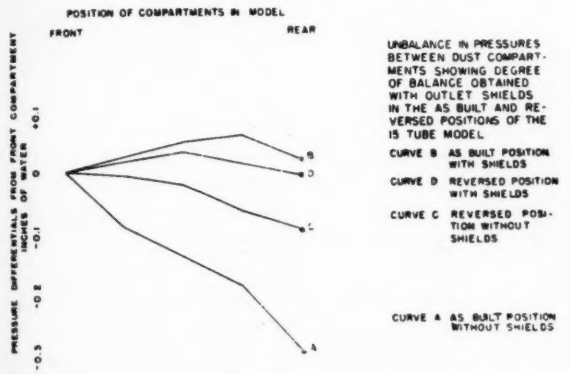
The most successful approach to reduce the inherent pressure differentials consisted of adding what are now

known as outlet shields to the individual tubes. Through a long series of tests, a shape for the shields was eventually established which reduced the maximum differential between any dust compartments to .06" w.g. or 1/5 of the maximum value without the shields.

Two slightly different conditions exist in full size units depending upon the relative direction of flow across the tube outlets. This comes about as the tubes all have the same direction of spin, but are arranged in alternately positioned banks such that the gas leaves the tube to the right from one bank and to the left from the next.

In the laboratory, we could reproduce either condition by reversing the inlet and outlet ends of the model. It was found that with the model reversed, a smaller degree of unbalance existed and the outlet shields, which had been developed for the first position, resulted in over correction.

Therefore, another shape was similarly developed to suit the reversed position, and at the same time be compatible with these first developed. This latter condition was important to permit application of both in the same unit. (See Curve No. 3 and Figure No. 7 showing data obtained for both positions with and without shields).


POSITION OF COMPARTMENTS IN MODEL
FRONT
REAR
PRESSURE DIFFERENTIALS FROM FRONT COMPARTMENT TO OUTLET
+0.1
0
-0.1
-0.2
-0.3
B
D
C
A
UNBALANCE IN PRESSURES BETWEEN DUST COMPARTMENTS SHOWING DEGREE OF BALANCE OBTAINED WITH OUTLET SHIELDS IN THE AS BUILT AND REVERSED POSITIONS OF THE 15 TUBE MODEL
CURVE B AS BUILT POSITION WITH SHIELDS
CURVE D REVERSED POSITION WITH SHIELDS
CURVE C REVERSED POSITION WITHOUT SHIELDS
CURVE A AS BUILT POSITION WITHOUT SHIELDS

Curve 3.

Shields

Explanation of the reasons for the shields producing this relatively high degree of balance is based partly on conjecture. However, it is apparent that in effect they form directional vanes which discharge the gas in the desired direction. This tends to streamline the flow and minimizes turbulence.

Also, they have an aspirational effect on the flow from front to rear. The data shows that they have reduced the differential from front to rear in the gas outlet compartment practically to zero, at the same time they have promoted balance in the dust discharge compartment.

Probably because of the reduction of outlet losses they have caused only a minor change in the overall pressure drop. Another effect of the shields, which is not thoroughly covered in any data yet available, is that they tend to improve top to bottom gas distribution by more properly

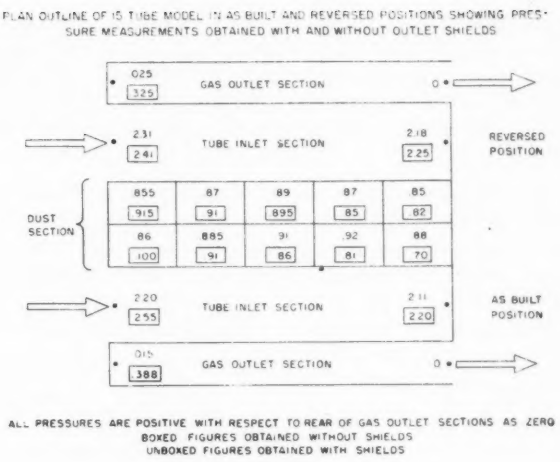


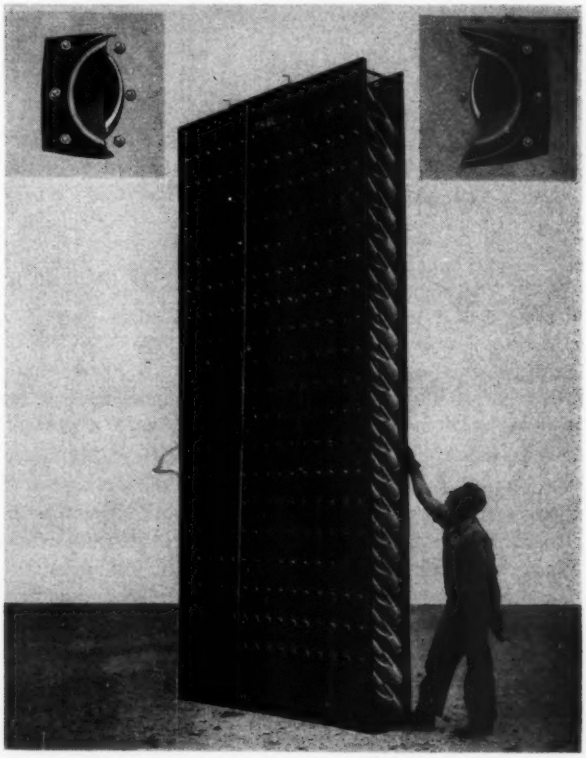
Fig. 7.

directing the outlet flow. (See Figure No. 8 showing shields installed on tube bank.)

In development of the shields every consideration was given to ease in applying them to existing collectors. Once access to the tube outlets is obtained, they can be installed merely by setting in place and adding two ¼" standard nuts on existing bolts.

The divisions in the dust discharge section of the model were removed, and efficiency tests were run in the two positions both with and without the outlet shields. The

Fig. 8.



results from 26 individual tests covered the range from 88.2 to 93.6% collection efficiency on a fly ash obtained from a pulverized coal-fired boiler and with collector pressure drops in the usual operating range. From these tests the average benefit attributable to the shields was .9%.

At present the laboratory investigations are continuing with a view to improve the shield design further. However, to permit early attainment of their anticipated benefits, production was started, and selected field applications were made as rapidly as possible. Observations of the first installations did not bring to light any serious complications, so the shields have since been installed on many existing collectors.

Regarding these shield applications, it should be remembered that they are primarily intended to reduce erosion through correcting a single source of recirculation. The effect on collection efficiency is expected to be minor although there is a definite potential benefit.

The few installations that are known to have been tested after installation of shields were subject to troubles of one form or another before installing the shields. In view of these conditions, as well as the difficulty of obtaining reliable comparisons, no conclusive evaluation of the shields from the standpoint of improving efficiency of full size units has yet been obtained.

Service Test Conducted

To permit comparative evaluation of the outlet shields in minimizing erosion under service conditions the cooperation of one customer was enlisted to conduct a service test. The installation was carefully selected, and was a new collector in which greater than average wear was expected based on available information about the anticipated operating conditions. For comparative purposes, the outlet shields were installed on all tubes of the collector served by one hopper and were left off a corresponding portion of the collector served by another hopper.

To immediately check for effects of the shields, a clean air flow was produced in the collector, while observers were closed into first one hopper and then the other to inspect the action inside the tubes. By introducing small quantities of dust inside the tubes, some evidence of recirculation could be seen in the rapidity with which the tubes cleared themselves of this dust.

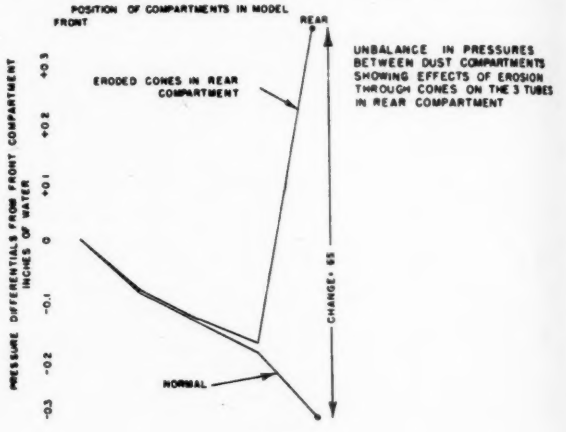
With the shields no dust remained spinning in any tube observed for more than a few seconds, and there was no noticeable difference from one portion to another. However, without the shields, dust did remain spinning in the rear tubes for longer periods and in the extreme rear bottom tube dust continued to spin indefinitely. This dust was still present 10 to 15 minutes after it had been introduced.

Only one subsequent inspection of this collector has as yet been possible. This was made after three months' operation, and the only wear present was a very slight rounding off of sharp edges at a joint in the tubes. There was a greater degree of this type of wear in the expected locations toward the rear of the tube banks without the shields than anywhere else. However, until a greater degree of wear is observed, these results are not considered conclusive.

Another general observation from several units inspected after installing the shields has been that the resulting patterns of dust deposits have been more uniform than those found in units without shields. The exact patterns observed are being considered in the development of an improved shield design.

Variations Cause Recirculation

Variations in shape from one tube to another are a cause of recirculation. One abnormal condition causing extreme variations in effective shape is tube erosion. To investigate this effect, a separate laboratory test was made by substituting three eroded-through cones in the rear compartment of the 15-tube model. A major change of .65" w.g. from the normal pattern of differentials resulted. (See Curve No. 4 which shows the complete patterns.)



Curve 4.

The effect of the eroded cones is considered especially significant as it shows how severe erosion, in a small group of tubes, can rapidly become progressive by causing recirculation into other tubes. Therefore, the appropriate course of action, when confronted with tube erosion from any cause, is to replace severely worn tubes at the earliest opportunity, while the number affected is still small and before the condition aggravates itself.

In conclusion, the subject matter covered herewith shows some of the efforts we have made to investigate internal flow problems which for years have been a major source of trouble in multiple tube centrifugal dust collectors.

In addition to investigating the problems, we have conceived, developed and applied devices known as outlet shields which are showing much promise for overcoming one cause of unbalance.

These shields were specifically intended as an improvement for one extensively used arrangement and design of existing collector. There is no question in our minds that the underlying principles involved are sound, although we believe that the shields themselves can be improved upon.

Beyond such direct benefits as may have occurred, we believe we are also bringing to light information which will permit a better general understanding of problems associated with multiple tube centrifugal dust collectors. This information should eventually result in long term benefit to future collector designs.

Avoidance of Atmospheric Pollution in Reclamation of Oily Aluminum Turnings

By R. E. Morken, Chrysler Highland Park Division,
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Shortly after World War II, in the face of a disturbed aluminum market, Chrysler Corporation decided to install equipment in order to reclaim aluminum scrap created in its manufacturing operations. This move was necessary at the time in order to maintain control of the extensive amounts of aluminum required for pistons.

Chrysler uses aluminum pistons in all its engines. About 75% of these pistons are cast in permanent molds in Chrysler's aluminum foundry. The remaining 25% are purchased from outside sources. All the pistons are machined in Chrysler plants.

These machining operations provide a volume of some 20,000 pounds per day of oily turnings. In addition to this, a variable amount of other scrap is available from the foundry operations, from die casting operations, and from sundry miscellaneous sources. The total scrap available is sufficient to provide approximately 60% of the metal necessary for the piston foundry.

In considering methods to be employed in the proposed reclamation facilities, several problems posed serious. Since such a large volume of metal was to be continuously recirculated within our plants, it was necessary to very closely control the extent of iron pickup in the metal.

Numerous laboratory tests run on our scrap materials indicated that approximately 0.30% of uncombined iron was present. Further tests showed that most of this iron was present in the form of very fine particles adhering to the oily aluminum chips. The source of this iron evidently was from abraded cutting tools. Of course this quantity of iron must be removed if the reclaimed scrap was to be used for pistons.

Magnetic Separation

Magnetic separation appeared to be the best solution to the problem of iron removal. However, in order to magnetically separate iron from oily chips, the chips must first be dried. Hence a survey of commercial drying installations was made, and close studies conducted.

It was observed that most of the installations examined had one or more difficulties present. We found the most economical and generally satisfactory method of drying oily chips was by means of a direct gas fired cylindrical rotating drum. Ordinarily, in these commercial installations, the oily turnings were fed into the drum at the end opposite the source of heat.

The chips were carried through the drum countercurrent to the heat by means of a helix welded to the inside of the revolving drum. An attempt was made to control heat input to the extent that the oil was vaporized from the chips rather than being burned.

This method controlled oxidation of the chips but caused much smoke. In addition, a severe explosion hazard was inherent in this method. Oily chips have a highly variable amount of oil present. The amount of oil is determined by the surface area of the chip; and, as the chip varies in thickness, the oil content per unit of weight is extremely variable.

Hence this method is difficult to control, and usually requires a considerable amount of manual adjustment of the equipment. Such considerations are not tolerable in the automotive industry, and moreover, we didn't feel we could locate an explosion hazard in the center of a plant employing several thousand people. The smoke condition prevalent in this method also was intolerable due to our location in a congested residential neighborhood.

Other Experiments

In view of the above drawbacks to the usual method, we ran a considerable number of experiments designed to remove oil by other means. Various combinations of washing and degreasing were tried. None of the experiments were satisfactory, because enough oil remained to cause the iron particles to adhere sufficiently to prevent magnetic separation.

Washing methods also caused a loss of material. Many of the thin aluminum chips floated on the washing solutions. Recovery of this floating material presented a difficult problem.

Once again, then, we turned to thermal removal of the oil. After due deliberation, we concluded that a drum type dryer could be used without hazard or nuisance if the

amount of oil on the chips were held reasonably constant. Again, an experimental program was launched. The ensuing results accomplished a substantial removal of oil by means of centrifugal separators, or chip wringers.

In this process, the chips are fed in batch lots into the basket of a chip wringer. Provision was made in the cover of the wringer to introduce steam and water. As the chips were spun, they were flushed first with a stream of cold water. This removed a large amount of oil and contamination.

Toward the end of the cycle, the water was turned off and 90-pound steam admitted for approximately two minutes. The chips were then spun until substantially no effluent was visible from the machine. Chips centrifuged in this manner were found to contain a very consistent residue of oil. Numerous batches were tested and contained from 2.1% to 2.3% oil.

Drying Operation Controlled

The results of these tests indicated the solution of our drying problem. Starting with chips containing a low and reasonably constant percentage of oil, the final drying operation could be controlled.

We reasoned that a drum type dryer could be used for this purpose if it were constructed in such a manner as to control both temperature and amount of air admitted.

We further reasoned that no explosion hazard could exist if a controlled excess of air were admitted to the drum; further, that no smoke would ensue if we burned, instead of vaporized, the oil in an excess of air at a controlled temperature.

Temperature control was essential also to prevent excessive oxidation of the chips. With these considerations in mind, a dryer was constructed using the conventional counter current principle. The combustion chamber was, in so far as possible, sealed to the drum. Chips were charged into the drum through a hopper having a controllable opening into the drum.

Since the damper across this opening impeded the flow of the chips, an electric magnetic vibrator was installed on the bottom of the hopper. Finally, a blower was installed to furnish combustion air to the burner. Off the combustion air line, a by-pass line, having an orifice and a needle valve, was fed into the drum above the burner.

This arrangement provided a controllable excess of air. Temperature control was provided automatically by means of a thermocouple at the flue. This thermocouple, in conjuction with a conventional pyrometer, was used to control a motorized valve on the combustion air line.

Helically arranged scoops were welded to the inside of the drum. In essence then, we had a drum substantially isolated from air, furnished with a controlled source of heat and air, and provided with means of stirring the chips and moving them through the drum.

Orderly Operation

This unit, in conjunction with the centrifugal separators, has been in operation continuously for the past six years. There has been no smoke and we have had no explosions. The chips have been thoroughly dried so that excellent magnetic separation has been attained. Iron pickup in the reclaimed metal has been negligible. Over 30,000,000 pounds of metal has been reclaimed since the equipment was started. We feel that this process has been a success.

Shortly after the reclaiming operations had begun, a very serious problem confronted us.

We discovered the roof of the plant in the immediate vicinity of the reclamation department was covered with very fine particles of aluminum. These fine particles when combined with rain water created a sort of metallic mud which did a most satisfactory job of clogging the downspouts and roof drains. Some of the mud found its way through the downcomers and created a very thorough mess in the sewers.

Immediate investigations disclosed that the fine particles of aluminum were being carried in the dryer air stream. A combination of air velocity and thermal velocity was sufficient to carry the particles up the flue and onto the roof.

At this time we had available in our plant a centrifugal type of dry dust collector. This collector was immediately installed in the exhaust stream from the dryer. Subsequent events occurred quite rapidly.

The metallic dust was effectively separated from the exhaust stream, but as soon as the proper concentration was attained a considerable explosion occurred. Fortunately no injury accompanied the explosion.

The equipment was cleaned, put back into serviceable condition, and provisions made to remove the dust as it was collected. Operations were resumed and peaceful conditions prevailed for a period of time. However, over a period of several weeks, a number of minor explosions, or pops," occurred. We decided that different means had to be installed to collect the aluminum dust.

Wet Type Collectors Successful

We have in the past used wet type collectors with a high degree of success on numerous jobs. Since we had available a unit of this type, constructed on the venturi principle, it was promptly installed to replace the dry collector.

We found the unit to operate with a certain degree of satisfaction for the first few hours. At the end of that time, aluminum dust was again coming out of the stack. What was happening, of course, was that the fine particles of aluminum were floating on the water bath.

From there they were picked up in the exhaust stream from the collector and blown up on the roof. After a considerable amount of consternation, an effective means was found to cope with this situation. We reasoned that if a

suitable amount of wetting agent could cause a duck to sink in a tub of water, we could obtain the same effect on aluminum dust.

Hence a small tank was welded to the water bath portion of the wet collector. A suitable gravity feed arrangement was provided, and a controlling valve installed in the feed line. The tank was filled with wetting agent, the valve cracked open sufficiently to cause a drip of wetting agent to enter the collector water bath, and operations began.

I am pleased to state that we now have a clean roof. The metallic dust is very effectively collected in this manner. It forms a sludge on the bottom of the collector. This is easily removed by means of a drag link conveyor which deposits the sludge continuously in a suitable container.

Tramp Iron Removed

A flow sheet of Chrysler Corporation's reclaiming facilities would show the incoming oily chips received in skid boxes approximately three feet wide, four feet long, and two and one half feet deep. These boxes are dumped into a conveyor system containing magnetic separators to remove tramp iron.

The conveyor deposits the chips into a surge hopper which feeds two centrifugal separators. After centrifuging, the chips are pneumatically conveyed to the dryer. The dryer discharges onto a bucket conveyor which feeds a double deck vibrating screen.

This screen removes all particles less than 30 mesh. We found this minus 30 mesh material uneconomical to recover. The headings from the screen are discharged onto a permanent magnet type of magnetic separator.

From here the chips, now dry and free of iron, are conveyed to large storage bins located above each of two Ajax-Tama-Wyatt twin coil induction furnaces. Electromagnetic type feeders control the discharge from the storage bins, and provide a controllable flow of material to the melting units.

With this arrangement we are able to feed chips to the melters at exactly the same rate at which the metal is melted. We feel this is important, since the chips would readily oxidize if allowed to remain floating on the molten metal. The metal is melted in batch lots running some 1700 to 1800 pounds per heat.

Each heat is fluxed before pouring into ingots. We use a chloride-fluoride base flux, and this presented a problem in preventing air pollution. A flux of this type gives off some very poisonous fumes which must be collected. For this purpose we installed a wet type of collector. The size of the collector and water flow through it were determined by the maximum amount of toxics in the exhaust stream from the furnaces.

In effect, what is being accomplished is this. The exhaust gases were found to contain quite appreciable amounts of chlorine and chlorides as well as a trace of fluorine. These gases being soluble in water, are collected in the water tank of the wet type collector.

A substantial flow of water is caused to pass through this tank, over a system of baffles to create agitation. The flow of fresh water is controlled to give a sufficient amount to cause dilution of the contents of the tank.

Finally the very weakly acidic water is flushed into our processing waste sewer where further dilution occurs. No difficulties have been encountered in this system since it was placed in operation.

Dross Skimmed

During the fluxing of the metal in the induction furnaces an amount of dross is formed on the surface of the metal bath. This dross is skimmed from the metal by means of perforated ladles. The dross is collected in refractory lined buggies having a tap hole in the bottom.

The dross buggies are wheeled under a hood and the dross is thoroughly rabbled. Exhaust from this hood is connected to the furnace exhaust system. After sufficient stirring has coalesced the small particles of molten metal contained in the dross, the tap hole in the bottom of the buggy is opened and the resulting molten metal is collected in a mold. This metal recovered from the dross is fed back into the induction furnaces for further refining before being poured into piston ingot.

The operations as outlined above, being continuous in nature, with no provisions for checking weights of material at the various stages of processing, offer no possibilities to determine efficiency of metal recovery.

We do, however, periodically run a weight check throughout the system. Average figures from such a check would show that chips as received in the reclamation department contain about 21% liquids. The liquids present are oil and water.

After centrifuging and drying, the dry chips contain approximately 1.50% of fines less than 30 mesh, and 0.30% of iron. Hence, the dry iron free chips represent about 77% of weight as received.

A breakdown of metal recovery in the melting operations shows that we recover from 94% to 96% of the weight of the dry chips. Of this amount some 6% comprises metal recovered from the dross. We use an average of 1% flux in the refining operations. Ash resulting from dross recovery is discarded.

The installation I have tried to outline has been a successful one. It has presented us with numerous taxing but interesting problems. We have successfully solved these problems as they have appeared.

The conclusions we reached and the methods of solving the air pollution problems incurred are certainly not the only means of accomplishing the end results.

We worked mainly with equipment at hand or readily available. Perhaps far better answers are available. If not at present, then certainly with such an outstanding group as this, striving toward solution of such problems, industry will have much to gain in future developments.

The Elimination of Dust from Asphalt Plants

By G. A. Mau, *Vice President*
The Johnson-March Corporation, Philadelphia, Pennsylvania

Practically all towns or cities are experiencing a new source of air pollution, due to the locating of asphalt or black top manufacturing plants in residential or industrial areas.

Transporting this material to the job is a costly item and usually confines the haulage distance to a radius of approximately 50 miles and requires railroad siding facilities. Black top is used for resurfacing old pavements. These and other reasons are conducive to locating in cities, towns or villages where most of the paving activity exists.

Little is known or written to the best of my knowledge about the effects of the dust discharged from pre-mixed bituminous aggregate plants, commonly known as asphalt or black top plants, other than it presents a nuisance in the surrounding areas of these plants. This is evident from the number of recent suits of common law in which fantastic claims have been made for all types of damages to houses, buildings, crops and manufactured products in industry, as well as the obscuring of vision on highways and railroads and the damage of breathing high concentrations of any kind of dust for long periods of time.

The asphalt or black top plant referred to in this paper is strictly confined to the manufacturing of bituminized aggregate for road paving or resurfacing of old pavements.

In the manufacture of black top, fine sand, crushed rock and similar materials are mixed with the asphalt or tar base to form a bituminized aggregate.

Hazards

The material used in this type of pavement that causes the hazard, nuisance or air pollution problem is the crushed sand or stone and the dust particles on the coarse aggregate.

The black top plant usually consists of:

(1) A drier for removing moisture from the sand and stone.

(2) Conveyors for loading the drier and removing the dried material to the storage bins.

(3) Mixing and weighing equipment for the proper proportioning of the asphalt tars with the sand and aggregate.

(4) Vibrating screens for separation of the aggregate.

(5) A fan and cyclone for exhausting the fines and dust from the drier.

Occasionally, some form of a scrubbing unit is used into which the dust from the cyclone exhaust is discharged for disposal.

It is this final phase of the operation of the asphalt or black top plant that causes the air pollution problem and is the basic topic of this paper.

Whether the sand and stone in the paving material is limestone, basalt, trap rock or granite, the resultant dust particles created in the revolving drier, vibrating screens and equipment for handling the material on the intake side of the drier constitutes a health hazard to the men working around this equipment and a nuisance to the neighboring dwellings or factories. Because of the large volume of dust discharged into the atmosphere, if proper methods are not taken to eliminate the discharge of the small dust particles, 30 microns minus, discharging from the cyclone exhaust, the dust problem can be even more severe. The larger particles from the cyclone discharge are re-used in the manufacturing process.

In order to understand what dust concentrations we are talking about, tests have indicated that dust loading in the average two-ton plant using a cyclone will discharge from five to nine grains per cubic foot. This is one of the heaviest dust loadings encountered in general industry.

While the state laws and regulations apply primarily to silica dust, insofar as the health hazard is concerned, those authorities most familiar with dust occurrence and its possible hazards recognize that the breathing of large quantities of dust is probably the greatest hazard to health likely to be found where dust is involved.

It is now becoming apparent that health will be affected when human beings breathe high concentrations of any kind of dust continuously.

The following test on particle size distribution of dust (S.G. = 2.75) made on an efficient cyclone collector will give you some idea of the particle size with which we are dealing:

Cyclone Efficiency—94.7%

Particle Size Distribution of Dust (S.G. = 2.75)

Fraction Microns	Escape Dust—%	Collected Dust—%
plus 45	1.1	84.0
—45 plus 40	.3	2.0
—40 plus 35	.4	2.0
—35 plus 30	.5	2.0
—30 plus 25	.7	2.0
—25 plus 20	1.5	2.1
—20 plus 15	2.1	2.1
—15 plus 10	4.5	1.9
—10 plus 5	12.9	1.4
—5	76.0	0.5

The degree of potential toxicity of the dust discharged is dependent upon the type of stone or sand used, whether it contains free silica and the quantity and size of escape dust particles.

Equipment and Efficiency Vary

The type of cyclone used and the efficiencies vary greatly from plant to plant. We have observed some plants where the cyclones collected only 12 to 15 tons per eight-hour day, whereas with proper efficiency, they should have collected approximately 18 tons per eight hour day. This very low collection efficiency might be due to bad cyclone design, improper installation, poor maintenance or worn-out parts.

The point I wish to bring out is that if the dust is not collected by an efficient cyclone, proportionately more will be exhausted into the atmosphere.

Since the dust collected in a cyclone is a usable size in the manufacture of black top material, efficient cyclones are a sound investment.

So far, we have discussed only generally the equipment used in the average black top plant, without discussing the dangers of material or particle sizes which constitute a nuisance when discharged into the atmosphere.

We have visited many asphalt plants this past year and talked with the operators. First, to determine whether these plants were a nuisance in the locality and, secondly, to learn how the escape dust or dust from the cyclone exhaust was being handled.

Our investigation revealed that this type is finding itself more and more the object of adverse zoning regulations in cities and villages, whether in the residential or industrial section of the towns. All signs point to the fact that local legislation and zoning ordinances will become more stringent in the future.

Plants without adequate facilities for the collection of dust from the cyclone exhaust—the plants without scrubber or electrostatic equipment—were being subjected to adverse litigation or under pressure for discharging dust particles and causing spots and stains on homes, as far as five miles from the black top plants. Where new housing developments are rising near a plant, a real problem exists, unless the dust and mist from the plant is successfully controlled.

We have heard it stated by men who have made a considerable study of dust prevention, that any atmosphere in which dust can be seen with the naked eye, is too dusty not only for health, but also in many cases, for safety and efficiency, and will always be a nuisance.

Many plants have installed some form of collector in addition to the cyclone, usually a scrubber tank with water nozzles spraying the gases and wetting the heavier solid particles, which are removed in the form of a slurry, while the fine sizes are discharged from the stack. This is not adequate dust control for the surrounding communities nor for health of men operating the plant. The difficult sizes to control or scrub from the gases are the 10-micron sizes, which are not removed in the ordinary scrubber mentioned previously, and require greater velocity scrubbing, impingement, centrifugal separation and the elimination of mist.

Proper Dust Collection

Requirements for the proper type of dust collection to meet the approval of state and local authorities on air pollution and hygiene should consider the following factors:

(1) The Particle Size

The large proportion of particle sizes—10 microns, may constitute a health hazard as well as a community nuisance.

(2) The ordinary scrubber utilizing water sprays does not capture the small particle sizes, because of the difficulty of wetting and agglomerating these particles.

(3) Provisions must be able to reduce the temperature and velocity of the gases. This requires a unit of ample size to permit repeated expansion and contraction of the gases and a series of scrubbing stages, which will aid in the agglomeration for the collection of the solid particles.

(4) All possible means for the collection of the small particle sizes should be utilized. These include inertial separation, impingement, centrifugal separation, filters, venturi scrubbers and mist eliminators.

(5) For maximum efficiency, a surface active agent should be utilized since it is impossible to wet and agglomerate the smaller size dust particles with plain water.

(6) Mist eliminators are essential to prevent the escape of dust particles less than 10 microns in size with the vapor or water droplets discharged from the stack. A fine spray might act as a carrier for small particle sizes.

Obviously from the above recommendations, a tank equipped with spray nozzles or other solid sheet spray methods, in which the gases pass through the spray is not sufficient to remove the 5 to 6% small micron size dust particles from the gas stream. A solid stream of water is a poor wetting medium particularly for fine particle sizes.

It is true, however, that a large percentage of the heavier dust particle sizes can be collected by this method. Coke bed filtering in tanks is one of the more common types of scrubbers in use and in some installations has given fair results after fresh beds of coke are properly arranged for even distribution of gases. The difficulty has been in keeping the coke bed from becoming clogged with solids and thereby increasing the back pressure on the fan. This type of scrubber needs constant maintenance for efficient operation.

Since many of the collectors are not efficient, scrubbers must be designed for heavy dust loading, and ponds large enough for storing and settling the slurry. If water is scarce or expensive and needs to be recirculated, the pond should have capacity enough to hold the solids and water

for settling to clarify recirculated water. Ponds we have found satisfactory are approximately 35′ x 50′ x 4′ deep.

Depending upon the type of asphalt manufactured, temperatures of gases leaving the driers will vary from 175 to 450° F. The average asphalt plant gas volume we have found to be approximately 28,000 cfm at 250° F.

Water Supply Must Be Adequate

In the many tests we have conducted to aid us in the design of our L.P. scrubber units, we have learned that unless excessively large volumes of water are used to reduce temperatures and thereby reducing the gas volume, the scrubbing out of small size particles was not too good.

Adequate water supply is always a problem. To purchase a water supply from 50 to 150 gpm is expensive and if a recirculation system is planned, large area ponds are required for settling.

The design of our unit requires approximately 2 gal/1000 cfm and we believe this to be the minimum to reduce temperatures and flush away the solids from the gas stream. This low water requirement is possible due to the expanding and contraction of gases passing through fine water sprays impinging with jet velocity on solid plates to shatter, and again wet by contact on the impingement plate, to agglomerate the solids from gas stream. This is what takes place in the first stage of the L.P. scrubber.

If the visible dust is eliminated, much of the invisible or probably the most dangerous dust will also be removed, and very likely the hazards minimized and the nuisance removed.

Therefore, it is important that black top plants make a sincere effort to stop all visible dust, not only from the cyclone, or other collector exhausts, but also the fugitive dust emanating from the drier intake conveyor and the vibrating screens over the bins.

It is certainly foolish to invest in collecting equipment which removes only a portion of the dust and discharges the remainder out into the atmosphere, creating a health hazard and dust nuisance.

The number of black top plants is growing constantly, and the dust problem is growing with them. Because so many plants are located in or near residential or industrial areas, or are being surrounded by the ever growing suburbs, the control of dust created by these plants will present an increasingly urgent problem.

The black top plant operators will find that complete dust control must be an integral part of the operation of their plants, if they expect to avoid costly litigation and the possibility of being zoned out of the areas in which they can profitably operate.

With the proper dust control equipment, there is no reason why a black top plant should not be able to comply with all local and state ordinances, and be as acceptable as any other industrial establishment.

Electrostatic Precipitation as Applied to the Cleaning of Gray Iron Cupola Gases

By Richard F. O'Mara and Carl R. Flodin
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Los Angeles, California

For many years the plume from a gray iron foundry cupola was accepted as a part of the normal industrial environment. However, with the increasing national importance of cleaner air and the means that have been set up through competent enforcement agencies, the cupola stack cleaning problem has been forcibly called to the attention of the dust recovery equipment manufacturers.

Simple mechanical collectors, spark arresters, or washers of various kinds were used for some time for the removal of the coarse material that settled within the plant or in the immediate neighborhood, but these had little or no effect on the stack appearance and recovered practically none of the fume. This is a major portion of the problem.

Investigations by the foundry industry, as well as dust equipment manufacturers, indicated that although the loss contained 10-15 per cent plus 44 micron material, 75-85 per cent was in the 0-10 micron fraction and under the microscope the majority of the particles in this fraction appeared to be spongy agglomerates in the range of 1-5 microns. For the removal of this fine material, cloth filters or electrostatic precipitators were indicated.

The data also showed that usually over 50 per cent of the material consisted of oxides of silica, zinc and lead.

It has been known in the non-ferrous metallurgical industry, practically since the beginning of electrostatic precipitation on a commercial scale about the year 1908, that the oxides of lead and zinc could not be satisfactorily precipitated without conditioning the gases. Later, pilot plant work in the treatment of gases from electric furnaces carrying high percentages of silica fume proved that this behaves similarly in an electric field and required humidification of the gases to get any satisfactory results. Realizing that the fume from a gray iron foundry cupola would require conditioning before treatment in an electrostatic precipitator, we decided to do our first pilot plant work with completely saturated gas.

Wet Cottrell Collection

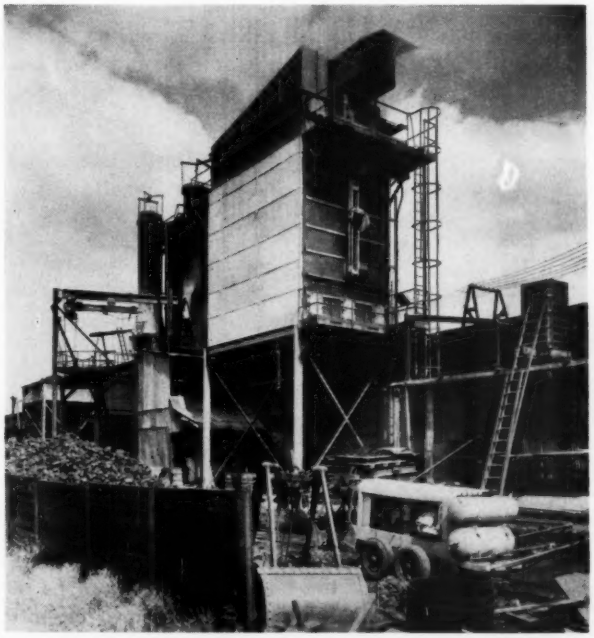
A wood pipe precipitator handling 3,000 CFM was built and tested on gases from a cupola after these had been passed through a scrubber to reduce the temperature to 150-160 degrees F. and practically saturated them. Tests on this pilot plant demonstrated that it was possible to obtain collection efficiencies in the precipitator of 97 to 98 per cent. This work was done the latter part of 1949 and the early part of 1950 in the Los Angeles area.

It soon became apparent, however, that the industry was unwilling to accept this solution of the problem for various reasons. The smoke plume was replaced by a steam plume. It is always difficult to explain to a layman that a steam plume from an industrial operation can be clean. In addition to the water requirements, a secondary problem in the disposal of the effluent and sludge added cost and complications. However, in many other industries the disposal of effluent and sludge from wet types of Cottrells is accepted as a necessary evil, since there is no other satisfactory way of removing the dust from the gases.

Dry Cottrell Collection

Since the foundry industry in the Los Angeles area was being pressed to find a solution and they were reluctant to proceed generally with any form of wet collection, it was decided that we would undertake the installation of a dry type Cottrell to operate in the range of 650 to 750 degrees F. on gases cooled and humidified in a conditioning tower between the cupola stack and the Cottrell inlet, Fig. 1. This installation was undertaken without a field pilot plant other than sufficient test work to determine proportions of a suitable conditioning tower. In this particular case the design data were as follows:

Cottrell Precipitator Outlet



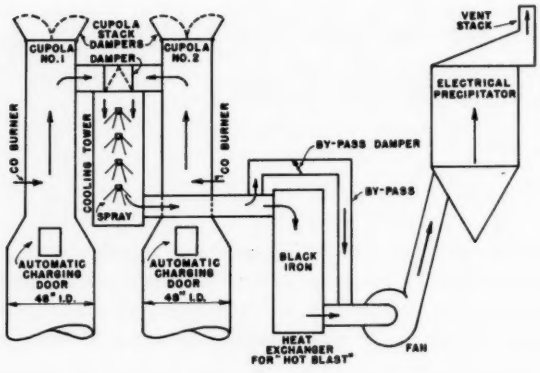


Fig. 1.

Cupola stack gas temperature	1000-1700° F.
Gas volume after conditioning tower	24,000 CFM 600-650° F.
Dust and fume loading	0.74 gr. per cu. ft. (152* per hr.)
Permissible loss—Total Solids	0.085 gr. per cu. ft. (17.5* per hr.)
Required collection efficiency	88.5 per cent.

The permissible dust and fume emission of 17.5 pounds per hour is based on the requirements of the Los Angeles County Air Pollution Control District calculated from process weights. This 17.5 pounds is a low outlet requirement when it is considered that it is contained in about 52,000 pounds of gas per hour. A cross-section of the dry-type Cottrell used on this job is shown in Fig. 2.

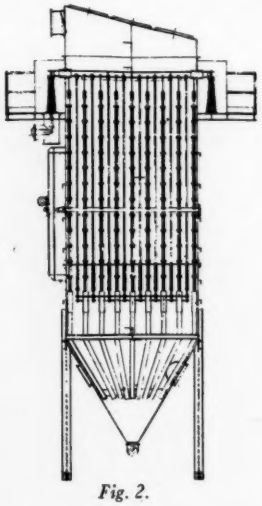


Fig. 2.

Gases enter at the bottom and pass up through a perforated distribution plate into ducts formed by 11.6-foot by 17-foot collecting electrodes on 15¾ -inch centers. The high voltage system consists of 3/16" square twisted rods.

The electrodes are of the tulip or pocket type and so arranged that the collected material is rapped off into dust slots, from which it falls into individual hoppers under each collecting electrode and is carried through the inlet gas stream in dust spouts into the main collecting hopper. The equipment is energized by means of a mechanical rectifier.

You are all familiar with the essential features of the Cottrell Electrical Precipitation process, so it will not be discussed in detail here.

Dry Cottrell Operation

In the interim between the time that the cooling tower and Cottrell were in fabrication and the time that they were placed in operation, the foundry management installed a heat exchanger in order to operate on a hot blast. This heat exchanger was placed behind the cooling tower. As a result of this change in the contemplated operating conditions, the gas at the inlet to the precipitator varied from 300 degrees to 420 degrees F. It was not possible to obtain satisfactory functioning of the collection equipment, since insufficient moisture could be added to the gas stream without adversely affecting the hot blast.

To remedy this condition, a by-pass was installed around the heat exchanger to demonstrate experimentally that with higher temperatures and moisture to the Cottrell it could be made to operate satisfactorily. This arrangement made a substantial improvement in the precipitator operations.

At the time the recovery installation was designed, the cupola was to be provided with top cover and charging doors to reduce infiltration as much as possible, and burners were to be installed in the cupola top to burn combustible gases. These accessories were eventually provided along with a damper to control the quantity of gases by-passed around the heat exchanger. Further test work developed the fact that due to the cyclic operation of the cupola, higher average gas temperatures were needed in the precipitator and wide temperature fluctuations were to be avoided.

After operations were smoothed out, tests on the installation indicated losses ranging from 11-15 pounds per hour, which were well within the range of the design requirements.

However, in addition to the regulations covering the permissible solids discharged per hour, the Los Angeles County Air Pollution Control Board have a further requirement covering opacity, or the comparison of the appearance of the stack with the Ringelmann chart—not on the basis of blackness, but on a basis of visibility through the plume.

The foundry was unable to obtain approval of the installation on a basis of the opacity of the stack. This was because the bulk of the loss from the precipitator was silica fume. This is all under 5 microns and has a very large light-reflecting surface.

Further adjustments in the installation, especially the smoothing out of the temperature and moisture characteristics of the gas at the Cottrell inlet, reduced the dust and fume loss from the precipitator from 17.5 pounds per hour to a range of from a loading of 2.7 to a high of 9.6 pounds per hour with efficiencies of 91.7 to 97.0 per cent.

Under these operating conditions, the installation easily met the Los Angeles regulations, both as to total solids emission and opacity.

Where opacity requirements similar to those in Los Angeles must be obtained, indications are that gas cleaning down to the range of 0.03 to 0.04 grains is necessary. Fig. 3.

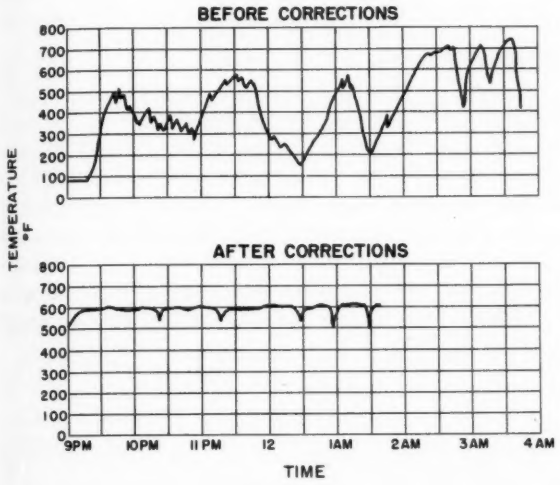


Fig. 3.

Early in the work, the importance of a reasonably well controlled temperature at the Cottrell inlet was recognized, and the necessity for this became more apparent when it was necessary to meet the opacity regulation. Fig. 3 shows the temperature variations during the course of heat before the regulating by-pass damper, insulation and burners were added to the system together with the temperature variations with the current normal operation.

Characteristics of Gray Iron Cupola Dust and Fume

At this point it may be of interest to review some of the pertinent data we have collected from various sources regarding the character of dust and fume emission from gray iron foundry cupolas. The design condition of the installation described in this paper is for an inlet dust and fume loading of 0.74 grains per cubic foot at stack conditions. It will be noted from Table I that this is more or less an average condition based on the results from eight different foundries. Some cases have come to our attention where the loadings are slightly lower than the values given in the table, and some where they are slightly higher.

TABLE I
DUST AND FUME EMISSION FROM GRAY IRON FOUNDRY CUPOLA

Foundry No.	Gr./Cu. Ft. at Standard Conditions
1	0.798
2	0.78
3	1.09
4	1.32
5	1.05
6	1.11
7	1.07
8	1.53

As has been mentioned earlier, the electrostatic precipitation industry has known for many years that it is extremely difficult, if not impossible, to precipitate silica fume without conditioning the gases, and that this is also true of some of the metallic oxides such as lead and zinc.

TABLE II
CHEMICAL ANALYSIS OF GRAY IRON CUPOLA DUST AND FUME

	Plant A	Plant B
Loss on ignition at 800° C. for 3 hours	17.53%	21.10%
SiO_2	31.28	37.54
R_2O_3	13.40	14.05
ZnO	15.37	10.18
PbO	8.90	9.98

In Table II it will be noted that the main constituents in losses from the gray iron foundry cupolas are those materials that are difficult to handle in a Cottrell without gas conditioning. The material represented by loss on ignition is probably coke fines from the cupola that are carried out in the gas in an unburned condition. The small amount of R_2O_3 represents other constituents, together with various iron compounds.

The specific gravity, particle size distribution, iron and silica content of material caught in the dry-type Cottrell hopper and the stack loss are given in Table III.

TABLE III
GRAY IRON CUPOLA DUST AND FUME SPECIFIC GRAVITY, PARTICLE SIZE, IRON AND SILICA CONTENT

	Hopper Catch	Stack Loss
Specific Gravity	2.94	3.12
Particle Size Distribution		
0-10 Microns	70.8%	91.0%
10-20 "	4.8	2.8
20-44 "	11.0	2.9
plus 44 "	13.4	3.3
SiO_2	34.6%	23.1%
Fe_2O_3	17.2	15.4

It is quite evident from both the high percentage of 0-10 micron material, as well as the predominance of high silica fume, that ordinary dry dust recovery equipment

other than Cottrells and filters will not be satisfactory where rigid stack clearance must be maintained.

Another index to possible difficulty of electrostatic precipitation of suspended solids from a gas stream is what is referred to as apparent electrical resistivity of the dust or fume. To determine this, a sample of the material to be studied is taken into the laboratory and precipitated on a plate and the electrical resistivity of the precipitated dust is measured in ohm-centimeters.

Generally speaking, it may be expected that there is likely to be trouble with precipitation of a dust when the electrical resistivity is in excess of about 10^{10} ohm-centimeters.* Figs. 4 and 5 apply to the same two plants as those referred to in Table II above covering chemical analysis of the dust and fume. It will be noted that the dust of Fig. 4 for Plant A reached a value of about 10^{10} ohm-centimeters at 450° F and that this resistivity was attained almost irrespective of moisture content of the gas stream.

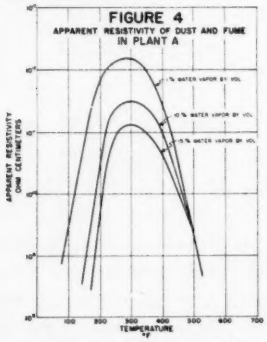


FIGURE 4
APPARENT RESISTIVITY OF DUST AND FUME IN PLANT A

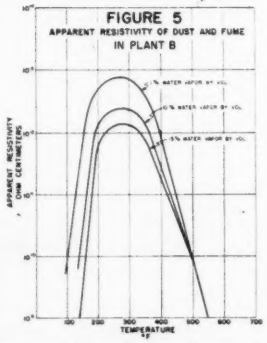


FIGURE 5
APPARENT RESISTIVITY OF DUST AND FUME IN PLANT B

As a matter of actual fact, the precipitator performance in Plant B turned out to be more critical of temperature conditions than of moisture conditions within the range of about 9 to 15 per cent water vapor by volume. With temperatures above 500° F. at the precipitator outlet, operation was satisfactory within a considerable range of moisture conditions.

It will be observed upon close examination of Figs. 4 and 5 that dust of Plant B has substantially higher resistivity than that of Plant A. With one per cent moisture, the dust of Plant B has a resistivity of 8×10^{12} at 270° F. and that of Plant A has a resistivity of 1.5×10^{12} at 280° F.

Conclusion

In this paper we have endeavored to outline the physical, chemical and electrical characteristics of gray iron cupola dust and fume discharge material and indicate the importance of these factors in the design and performance of Cottrell Electrical Precipitation Equipment.

Where a high efficiency is required in the removal of dust and fume constituents from gray iron foundry cupola gases to meet exacting regulatory requirements covering solids emission, as well as opacity, the data outlined, together with the successful operation of commercial installations, demonstrates that the Cottrell Electrical Precipitation process is a practical, satisfactory solution to the problem.

*For a more complete discussion of apparent electrical resistivity of dusts and fume refer to references 3, 4 and 5 in the bibliography at the end of this paper.

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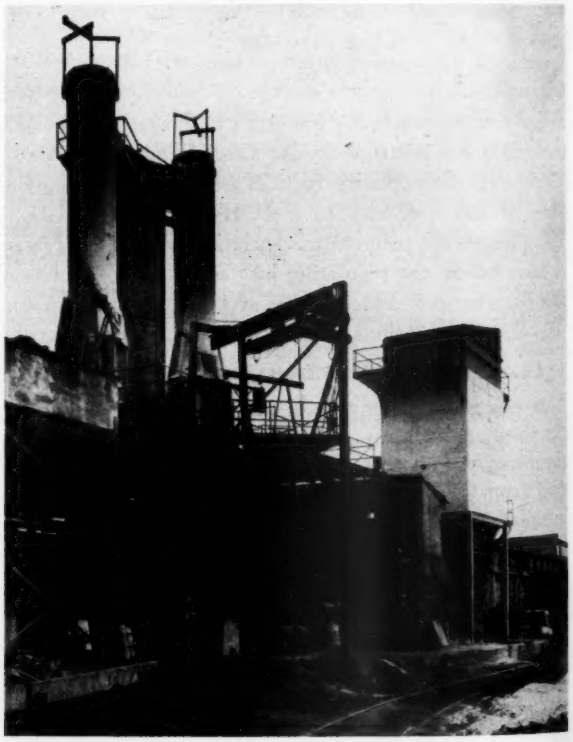
Conditioning tower between cupola stacks with Cottrell precipitator at right



Experimental Study of Effects of Tangential Overfire Air on The Incineration of Combustible Wastes[1]

By
R. C. Corey[2], L. A. Spano[3], C. H. Schwartz[4], and Harry Perry[3]

Introduction

An urgent need for systematic fundamental and engineering studies of incineration has resulted from growing emphasis on air-pollution control in municipalities, expanding operations of the United States Atomic Energy Commission, and increasing use of radioisotopes in private and public institutions not connected with atomic energy sites.

The prime requisites of incineration are: (1) Maximum combustion efficiency, so that smoke, tars, and malodorous constituents are not discharged to the atmosphere. (2) Maximum retention of particulate matter within the combustion chamber, to obtain the lowest possible dust loading in the stack gases. (3) Maximum reduction of volume of refuse, so that the least amount of residue must be handled.

The Atomic Energy Commission, cognizant of some of the difficulties in meeting these requirements, and of some additional problems unique to the disposal of refuse contaminated with radioisotopes, requested the Bureau of Mines to undertake a systematic investigation of incineration. The broad objectives of the investigation were to determine the effects of certain process variables on the performance of a relatively small-scale incinerator, and finally to design a prototype incinerator on the basis of the results of the model studies. The model studies are nearly completed; a prototype unit has been designed and constructed, and performance tests are being made.

It is believed that certain of the results and conclusions from the model studies may be of immediate interest to manufacturers and users of incinerators, and municipal air-pollution-control bodies. Ultimately, it is hoped that the performance data of both the model and the prototype incinerators will correlate in a manner to provide generalized design parameters. For the present, however, it must be emphasized that the data in this paper apply only to the model unit and may be used with reasonable confidence to design units of similar size.

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G. R. Kollar, Engineering Aid, Combustion Research Section.

N. C. Kibsey, Laboratory General Mechanic, Combustion Research Section.

Background

Knowledge of the complex heat and mass-transfer processes that control combustion in solid-fuel-fired furnaces is meager. Nevertheless, certain empirical principles regarding combustion in fuel beds have evolved over a period of many years both from fundamental studies of different types of fuel beds and a wealth of engineering data from performance tests in a variety of industrial furnaces. Consequently, it is not difficult to design an industrial furnace for a fuel of known characteristics and a given heat-release rate.

However, in the field of incineration no sound engineering data have been published that would provide empirical design parameters, partly because performance requirements have not been as rigid in the past as in recent years, and partly because the problem is so difficult, owing to the unusual operating characteristics of incinerators. Generally incinerators are required to perform satisfactorily over a wide range of operating conditions. For example, the refuse charged to them is heterogeneous, consisting of different kinds and proportions of solid and semi-solid wastes; consequently the heat of combustion and the burning characteristics may vary widely. Moreover, when incinerators are charged at random intervals

with varying quantities of refuse, the flow rate and the distribution of air through and above the ignited charge are radically changed, with the result that the effective temperatures within the combustion chamber fluctuate widely. The incinerator must accommodate these characteristics, or there will result intermittent discharge to the atmosphere of solids, aerosols, and malodorous gases, arising from incomplete combustion. In this connection, it should be noted that analyses of effluents from a variety of municipal and domestic incinerators have revealed relatively large concentrations of aldehydes, nitrogen oxides, tarry organic constituents, and solids.[4] [5]

Observations of a variety of types and sizes of incinerators have clearly indicated that unsatisfactory performance is largely the result of inadequate control of the flow rate and the distribution of air through and above the charge, and of indaquate provision for heat transfer to the charge during the preignition period. Moreover, air-fuel ratios often are far in excess of those in properly operated coal-burning furnaces, which results in low flame temperatures, and, for a given design, excessive gas velocities with respect to retention of particulate matter. The causes of these deficiencies in relation to incinerator design have been discussed elsewhere.[6] However, some of the important factors in connection with problems of air distribution and heat transfer merit brief discussion, since they bear upon the experimental procedures described in this paper.

Other things being equal, control of the amount and distribution of overfire air is extremely important from the point of view that the rate of mixing of oxygen with the combustibles from a burning fuel bed governs the size and shape of the flame and therefore determines to a large extent the volume required for complete combustion. The rate of mixing and the degree of turbulence in a non-isothermal system are functions of such aerodynamic factors as friction, inertia, and buoyancy of the gases.

There are no simple methods of measuring turbulence quantitatively under the conditions that prevail in large combustion chambers, and its effects are generally correlated empirically with certain characteristics of the devices employed to promote turbulence. For example, a number of equations have been proposed for jets, which contain terms for the number, diameter, angle of inclination, and distance above the fuel bed, of the jets, as well as for the mass flow of both the air through the jets and the products of combustion through the chamber.

The problems of mixing in combustion chambers are complex, and although some progress has been made through model studies and the use of the principles of dynamic similitude, the industrial application of turbulence promoters in conventional furnaces is still based largely upon cut-and-try methods. Insofar as incinerators are concerned, the problem is made even more difficult by the variations of temperatures and gas mass-flow rates during the burning period.

High rates of heat transfer are necessary to establish active burning as soon as possible and to provide gas temperatures high enough to crack the volatiles and burn the resulting products. Unless sufficient heat is transferred during the preignition period, excessive quantities of tars, tar acids, and gases escape unburned and produce a characteristic yellowish-to-white, acrid, smoke, even though enough oxygen is present to effect complete combustion. Certain types of incinerators provide secondary combustion chambers to burn pyrolytic products that escape the primary chamber. Although such chambers are satisfactory in principle, rarely do they accomplish this purpose. This is largely the result of the fact that very little is known about the combustibility of volatile matter; consequently, there is no rational basis for the design of secondary chambers. The problem is complicated by the fact that both the composition and the yield of the primary pyrolytic products from a given material vary with the temperature at which they are formed, and if the temperature of the environment is high enough, secondary reactions take place and further alter the composition of the products.

Heat transfer occurs mainly by radiation from the flame of the burning charge and by re-radiation from hot refractory that the charge "sees." In the absence of sufficient flame, as when the fraction of the burning surface is too small, the refractory, or an auxiliary flame, must provide the necessary heat. However, under unsteady-state conditions of heat transfer, which are implied in random charging, it is evident that adequate design of the combustion chamber would be largely fortuitous, and a properly placed auxiliary flame is necessary to supplement the heat transfer from the refractory.

This discussion of the aerodynamic and heat-transfer factors is related to the generally known fact that temperature, gas residence or contact time, and turbulence are the essential parameters in gas-phase combustion, other things being constant. The aerodynamic factors are the most difficult to evaluate; and for reasons that will be discussed later, it was decided that a different approach to the problem of gas mixing in incinerators would be desirable.

Plan of Investigation

Several factors had to be considered in designing an incinerator for the Atomic Energy Commission, such as handling the residue, which has been reported upon,[7] and the design of the gas-cleaning system. However, the most

[4]Third Interim Report on the Smog Problem in Los Angeles County, Stanford Research Institute. 1950.

[5]Technical Bulletin No. 6, Municipal Incineration, University of California, November 1951.

[6]Corey, R. C., Some Fundamental Consideration in the Design and Use of incinerators in Controlling Atmospheric Contamination, AIR POLLUTION, pp. 395-407, L. C. McCabe, Editor, McGraw-Hill Book Company, New York, New York.

[7]Corey, R. C., Perry, H., and Schwartz, C. H., Off-Site Disposal of Radioactive Incinerator Residues by Solid Fluxes: Amer. Ind. Hygiene Assn. Quarterly, Vol. 12, No. 2, June 1951, pp. 52-57.

urgent need was to achieve maximum possible combustion efficiency and retention of particulate matter, consistent with a reasonable burning capacity. Accordingly, the design of the combustion chamber was carefully considered from this standpoint. Some possible basic design features were suggested by the characteristics of typical refuse. For example, the low bulk density, low ash content, and relatively high yield of volatiles suggested that equilibrium burning (that is, simultaneous ignition and burning on the surface) might be accomplished by supplying most or all of the air above the bed. This would eliminate the problems of fluctuating pressure drop through the fuel bed and of uncontrolled flow of air through uncovered grate areas.

Since the mass flow rate and the direction of the overfire air would have to be carefully controlled to avoid excessive discharge of entrained particles of ash and char from the chamber, it was decided to introduce the air through tangential ports located above the level of the charge, in a cylindrical combustion chamber, with a small axial outlet pipe at the top of the chamber. The unit thus would resemble a cyclone-type dust collector and therefore would have similar fluid-flow characteristics; that is, there would be some vertical gas recirculation close to the walls and a core of gases rotating with constant angular momentum (free-vortex).

This mode of gas flow above the fuel bed appeared to have several advantages with respect to both the burning process and the retention of particulate material. For example:

1. Constant angular momentum implies that both the radial and tangential velocities increase as the gases sweeping the surface of the bed approach its center. For a fixed mass flow rate of air through the ports, thus fixing the mean radial velocity, the mean tangential velocity can be increased merely by reducing the area of the ports. These phenomena imply high relative velocities with respect to the surface of the fuel, which are necessary for scrubbing the fuel surface to reduce diffusional resistance and for complete mixing of the combustibles with oxygen.

2. For a given net linear gas velocity through the chamber, entrained particles of char would travel a longer path than if there were no angular flow components and therefore would have a better chance to be consumed. Moreover, the radial and centrifugal forces exerted on particles entrained in the gas stream would result in a certain amount of solids retention.

3. Air flowing downward along the walls of the chamber, which is characteristic of cyclone chambers, would acquire a certain amount of preheat as the result of convective heat transfer from the walls and possibly some radiation from the luminous flame above the charge.

4. Owing to the relationships between the linear flow conditions in the inlet ports and the distribution of tangential velocity in cyclone chambers,[8] it would be possible to correlate the burning characteristics directly with independent variables that are of primary interest to designers, such as the size and location of the tangential ports for a given air rate.

A prototype unit might first have been designed for a given heat release rate and grate loading, with full recognition of the fact that the performance tests undoubtedly would suggest various changes. It was decided, however, to make the preliminary studies in a smaller unit, which could be changed more easily and quickly than a full-scale unit. This procedure had the additional advantage of providing data that would make it possible to evaluate the scale factors, since the geometric ratio of the model to the prototype would be roughly 1:5.

Scope of Investigation

The tests were designed to correlate the burning characteristics with independent variables, such as the air-flow rate through the tangential ports, the discharge area of the ports, and the height of the ports above the fuel bed. Accordingly, tests were made with three different air-flow rates, and for each flow rate three different discharge areas and four different heights of the ports were used. Approximately 50 tests, including checks, were conducted for this phase of the work.

The principal observations were: (1) The time required to burn a given weight of charge completely, (2) the composition and the temperature of the products of combustion, (3) the composition of the gases at various locations *within* the combustion chamber, (4) the smoke and tar in the products of combustion, and (5) the temperature distribution over the metal shell of the incinerator. The results of the latter measurements are not included in this paper, because analysis of data is not yet completed.

The quantities used to characterize the performance of the unit were: (1) the *observed* burning rate, that is, the pounds of charge consumed per hour, as denoted by the elapsed time between ignition and complete burnout of the weighed charge; (2) the *calculated* burning rate, derived from the gas analyses and the air-mass flow rate, which represents only that part of the charge which is burned to carbon dioxide and water. (3) the fuel-air ratio, derived from the calculated burning rate and the air-flow rate.

A series of tests also was made to determine the distribution of tangential velocity in the incinerator for various air-flow rates, port areas, and port heights. The object of this phase of the work was to establish the relationship between the angular flow conditions within the incinerator and the linear flow conditions in the tangential ports. These tests were made with cold air and without combustion.

To eliminate the composition of the fuel as a process variable, wood sawdust of relatively uniform composition and size consist was used for all of the burning tests. Its

[8]Stairmand, C. J., Pressure Drop in Cyclone Separators: Engineering, October 21, 1949, pp. 409-412.

bulk density was about 10 pounds per cubic foot, and its proximate analysis on the as-fired basis was nominally 8 percent moisture, 74 percent volatile matter, 17.5 percent fixed carbon, and 0.5 percent ash. The gross heating value was 8200 Btu per pound. A few exploratory tests were made of a mixture of rubbish and garbage, for purposes of comparison.

Experimental Apparatus

The model incinerator used for the tests is shown schematically in figure 1. It was constructed from a 55-gallon stainless-steel drum. Two tangential air ports, 180 degrees apart, were located at each of four different levels, each port being valved and connected to a manifold so that any pair or combination of pairs could be used at any time. Machined inserts in the ports made it possible to select discharge areas 0.00166, 0.003 or 0.006 square foot, or approximately in the ratio of 1:2:4.

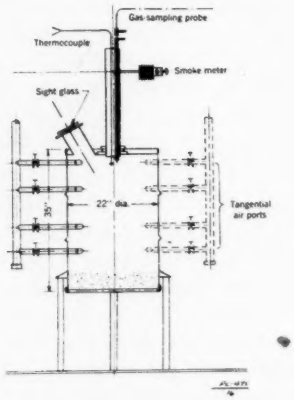

Fig. 1. Schematic diagram of the model incinerator.

The observation hole was of ample size to observe about one-half of the fuel bed and to make time-lapse photographs.

Access holes, not shown in the figure, were located at three elevations on one side. Water-cooled probes were inserted through these holes to secure gas samples at various positions radically and vertically during the tests.

A thermocouple was inserted through the stack, with the hot junction approximately flush with the inlet to the stack. Owing to its location, this couple provided only an approximate indication of the gas temperature, which was adequate for the purpose of these tests.

A water-cooled gas sampling line also was located in the stack to provide a continuous gas sample for a CO_2 recorder and an average sample for complete orsat analysis.

A Bacharach smoke indicator in the stack drew a measured volume of stack gas through a paper disc and provided a relative measure of smoke and tars in the gases at any selected time.

Several thermocouples were welded to the outside of the shell to provide a continuous record of the shell temperature at selected positions.

The velocity surveys mentioned previously were made with an airfoil pitometer designed by the Harvard School of Public Health and loaned to the Bureau by Dr. Leslie Silverman, Associate Professor of Industrial Hygiene.

Experimental Conditions

Before discussing the results of the experiments with the model incinerator, it is important to emphasize certain features of the tests that should be considered in evaluating the results.

1. The combustion chamber contained no refractory; and no auxiliary fuel was burned, other than a small quantity of kerosene to ignite the sawdust at the start of each test. (The amount used was too small to contribute significantly to the total heat release.) Accordingly, the primary source of radiant-heat transfer was the flame of the burning charge, and the heat losses from the shell were relatively high.

2. The unit was charged once each test with 10 pounds of sawdust and the test was considered to be completed when the last embers were seen to burn out, as noted through the observation port. A few tests also were made with larger quantities of sawdust, to determine in a preliminary manner the effect of initial bed height, and with lunch-room refuse for comparative purposes.

3. Smoke, tar, and other particles were estimated on a relative scale by means of the paper discs. Moreover, visual observations of the fuel bed and the stack effluent throughout each test, in conjunction with the continuous record of exit-gas temperature and CO_2, indicated reliably the burning conditions at any instant.

Experimental Results

It was mentioned previously that the purpose of this paper is to give such results and conclusions of this investigation as might be of interest to designers and users of incinerators, and municipal air-pollution-control bodies. Therefore, detailed information data showing instantaneous values of the different variables are omitted, but will be given later in a comprehensive paper describing the results of both the model and the prototype units. Except where indicated otherwise, the burning rates, temperatures, and other variables are averages for each entire test.

The simplest correlation is the change in the observed burning rate as a function of the actual air rate, with the area of the tangential ports as a parameter. This is shown in figure 2, from which it is evident that the observed burning rate increased as the air rate increased and as the port area decreased. The theoretical burning rate, shown as a broken line, is the rate that the sawdust would burn completely to CO_2 and water vapor at a given air rate, if no excess air were necessary. It is computed by dividing the actual air flow rate by the theoretical air/fuel ratio, which depends upon the composition of the fuel. It is an approximate guide to the maximum achievable rate of complete combustion of the fuel. Observed burning rates

that lie appreciably above this line suggest that some of the fuel disappeared as unburned combustibles. If combustion is complete, the burning rates may lie on or below this line, and the distance below it is relative measure of the excess air. It is possible however, to have unburned combustibles in the presence of excess air.

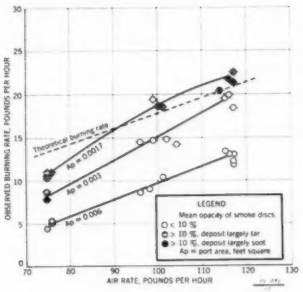
OBSERVED BURNING RATE, POUNDS PER HOUR
AIR RATE, POUNDS PER HOUR
Theoretical burning rate
Ap = 0.0017
Ap = 0.003
Ap = 0.006
LEGEND
Mean opacity of smoke discs
○ < 10 %
◑ > 10 %, deposit largely tar
● > 10 %, deposit largely soot
Ap = port area, feet square

Fig. 2. Average observed burning rate as a function of air rate and port area.

Analysis of the data failed to disclose any effect of the height of the ports above the fuel bed on the observed burning rate. It will be shown later, however, that this variable does have a small effect upon the calculated burning rate, that is, the burning rate computed from the composition of both the sawdust and the flue gases and the air mass flow rate.

During each test several smoke measurements were made at regular frequent intervals with the Bacharach instrument. The relative opacity of each paper disc was measured photometrically, and the results were averaged for each test to obtain an overall relative smoke value. These values are a relative measure of the amount of smoke and tar in the flue gases and are a qualitative indication of the combustion efficiency. Arbitrarily, it was decided that conditions were satisfactory when the average relative opacity was less than 10 percent. These are represented by the clear circles in figure 2. Values greater than 10 percent are either hatched or solid circles, depending upon the color of the paper discs, brownish indicating tars and gray to black indicating soot.

Smoke and tars were least with the intermediate and highest air rates, in conjunction with the intermediate and largest port areas.

Tarry products occurred in the flue gases at the lowest air rate (about 75 pounds per hour), regardless of port size, which suggested that either the volatiles and oxygen were insufficiently mixed or the temperatures in the combustion zone were too low, or both. Tars and smoke also occurred at the intermediate and highest air rates when the smallest ports were used. Under these conditions the swirl of gases over the fuel bed was observed to be pronounced, and the center of the fuel bed, comprising roughly one-tenth the area of the bed, appeared to be cooler than the outer portion. One explanation for these phenomena is that the high tangential velocities resulted in sufficiently high burning rates to consume the oxygen before the air traversed the bed, and the central portion of the bed merely carbonized and the volatiles did not burn. Experiments to confirm the disappearance of oxygen under these conditions are discussed later.

Small quantities of CO and H_2 in the flue gases, with the highest air rate and smallest ports, suggested that the temperatures were high enough to crack the volatiles.

Since the observed burning rate correlates with both the air-mass flow rate and the size of the tangential ports, the use of a dimensionless group for the latter variables was suggested, thereby reducing the number of variables by one. Reynolds number,* Re, which frequently is used to correlate the flow of fluids through conduits with other variables, was employed for this purpose. In figure 3 both the observed and the calculated burning rates are plotted as a function of the Reynolds number of the air in the tangential ports, and the correlation is seen to be good.

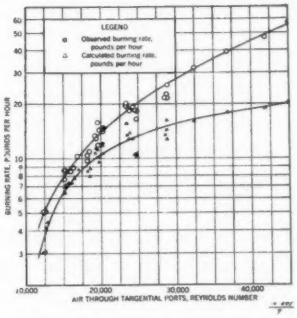
LEGEND
Observed burning rate, pounds per hour
Calculated burning rate, pounds per hour
BURNING RATE, POUNDS PER HOUR
AIR THROUGH TANGENTIAL PORTS, REYNOLDS NUMBER

Fig. 3. Burning rate as a function of Reynolds number of air in tangential ports.

Since the observed burning rate represents all of the fuel that is consumed, and the calculated burning rate only the portion that burns to CO_2 and water, the spread between these curves is related approximately to the amount of combustible material in the stack gases. It is evident that the spread is least, that is, the combustion efficiency was greatest, at the lower Reynolds numbers. This is shown more clearly in figure 4 where the ratio

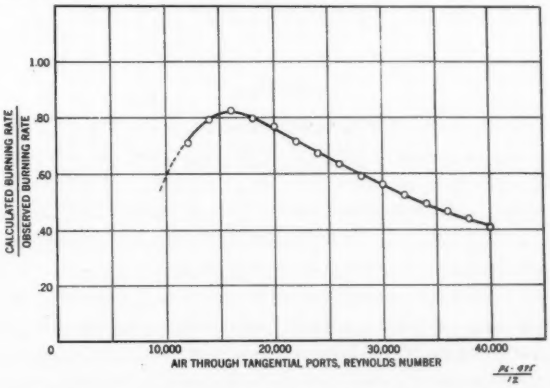

Fig. 4. Combustion efficiency as a function of Reynolds number of air in tangential ports.

*Re=DG/μ, where D=equivalent diameter of the port, G=mass flow rate of the air, and μ=viscosity of the air, all in consistent units,

of the calculated burning rate to the observed burning rate is plotted as a function of Reynolds number. Evidently the optimum value is roughly 15,000.

Previous discussion related to average burning rates for the various tests. It is of interest to consider the instantaneous values of the burning rate, computed from gas samples taken at frequent intervals. These are given in figure 5, together with the CO_2 values, for a typical test.

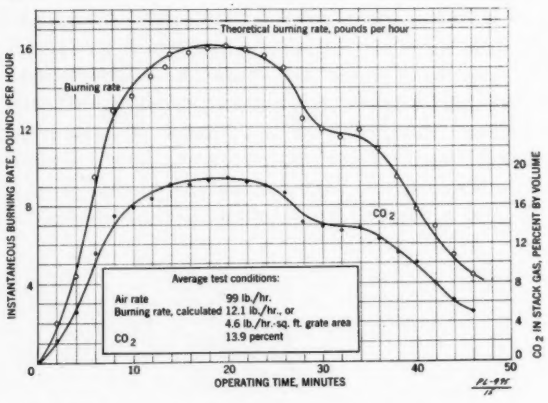
Theoretical burning rate, pounds per hour
Burning rate
CO_2
Average test conditions:
Air rate 99 lb./hr.
Burning rate, calculated 12.1 lb./hr., or 4.6 lb./hr.-sq. ft. grate area
CO_2 13.9 percent
INSTANTANEOUS BURNING RATE, POUNDS PER HOUR
CO_2 IN STACK GAS, PERCENT BY VOLUME
OPERATING TIME, MINUTES

Fig. 5. Instantaneous burning rates and CO_2 for a typical test.

For comparison, the theoretical burning rate, which is based upon the ultimate analysis of the sawdust and the given air rate, also is given. These results may be summarized as follows:

1. The maximum burning rate is roughly 94 percent of the theoretical value and the CO_2 is correspondingly high.
2. The average burning rate is 70 percent of the theoretical value.

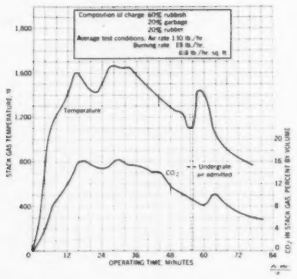

Fig. 6. Instantaneous values of stack gas temperature and CO_2 for a test with prepared refuse.

These relations were somewhat different for various test conditions when burning sawdust, but the trends were generally similar to those shown in figure 5.

An exploratory test was made with a prepared refuse containing rubbish, garbage, and rubber, in the weight proportions given in figure 6. Since the ultimate composition of the charge was not determined the instantaneous burning rates could not be calculated from the gas analyses. But the stack-gas temperatures are proportional to the burning rates, and it will be noted that the general trends were the same as with sawdust. A short blast of undergrate air was admitted after 55 minutes, and the gas temperature and CO_2 rose, suggesting that the bed was disturbed and fresh surface of the fuel was ignited. Neither smoke nor odor was noticeable during this test.

The effect of air velocity on the oxygen distribution and the burning conditions in the combustion chamber can be characterized by the composition of the hot gases sweeping the surface of the burning charge. Figure 7 shows the composition of the gases at different elevations inside the incinerator when burning sawdust at the same air rate of 117 pounds per hour, but for two different port

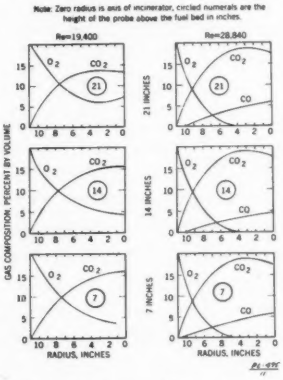
Note: Zero radius is axis of incinerator, circled numerals are the height of the probe above the fuel bed in inches.
Re=19,400
Re=28,840
21 INCHES
14 INCHES
7 INCHES
GAS COMPOSITION, PERCENT BY VOLUME
RADIUS, INCHES

Fig. 7. Composition of gases within incinerator for different Reynolds numbers. Air mass flow rate constant at 117 pounds per hour.

velocities—35.8 and 130.8 feet per second. The measurements were made about 15 minutes after the start of each test, which is approximately when the instantaneous burning rate is highest. The figures on the left side are for a velocity of 35.8 feet per second and on the right side for a velocity of 130.8 feet per second. The respective Reynolds numbers are 19,400 and 28,840, the first being near the optimum value shown in figures 3 and 4 and the latter sufficiently higher to result in appreciable unburned combustibles.

It will be noted that excess oxygen was present from the wall to the center of the chamber and from the top to the bottom, for the lower velocity. At the higher velocity the oxygen disappeared about 4 inches from the center of the fuel bed and carbon monoxide increased toward the center. Observation of the fuel bed under these conditions revealed a relatively cold spot at the center of the bed, indicative of lack of oxygen. Although there was evidence of distillation of volatiles from this area the stack gases were clear, suggesting that temperatures were high enough to crack the volatiles.

During these tests the temperature and the CO_2 content of the stack gases were determined at regular intervals. In addition, the relative smoke was measured as described previously, the fractional transmission of light through the

paper disc being used as an index of smoke density. A value of 100 represents a clean disc.

In figure 8 the results are given for 35.8 feet per second (Re=19,400). The shaded circles above the light-transmission data are photographic reproductions of the corresponding smoke discs. The results for 130.8 feet per second (Re=28,840) are given in figure 9. The gray shade of the discs agrees quite well with the corresponding transmission data in both figures. Since the photographs

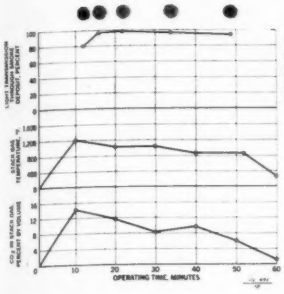

Fig. 8. Stack conditions for port velocity=35.8 fps, air rate=117 pounds per hour, Re=19,400.

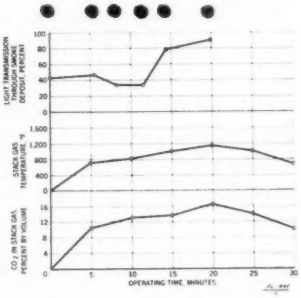

Fig. 9. Stack conditions for port velocity=130.8 fps, air rate =117 pounds per hour, Re=28,840.

of the smoke discs were made by reflected light, and the data were obtained by transmitted light, some discrepancy between the two may be expected where the discs have a brownish color.

Comparison of figures 8 and 9 shows that the combustion efficiency was better when Re=19,400, which is close to the optimum 15,000, mentioned previously. It should be mentioned, however, that in neither test were smoke conditions objectionable in the usual sense; small quantities of smoke and tar will produce heavy discoloration of the Bacharach discs under the conditions that the instrument was used.

This is by no means a complete analysis of the many factors that were investigated in connection with the model studies. For example, the effects of such variables as the geometry of the ports and the height of the ports above the fuel have not been discussed. Nor have the results been given of the velocity traverses made to establish the relationship between the flow pattern in the incinerator to the linear flow conditions in tangential ports. These data are now being correlated, and it is too early to discuss the final results. However, in this connection figure 10 shows the fuel-air ratio as a function of the tangential velocity of the gases at a radius in the chamber corresponding to the circle to which the tangential ports are tangent. The theoretical line is fuel-air ratio for zero excess air. The maximum in the curve corresponds to 40 percent excess air and suggests that the optimum tangential velocity close to the wall of the incinerator is about 14 feet per second.

Additional data show clearly that, below some minimum port area, the transfer of the linear momentum of the air in the ports to angular momentum of the gases in the chamber is zero, regardless of the linear velocity in the tangential ports. This is suggested by figure 11, where the

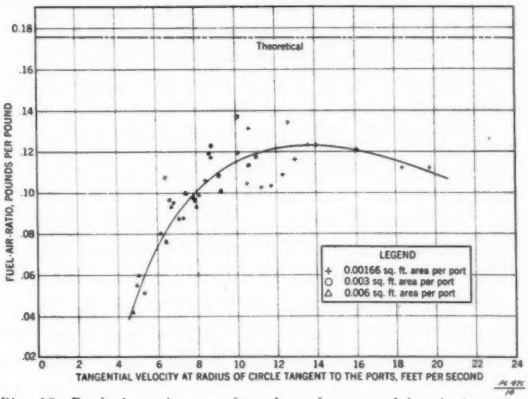
Theoretical
FUEL-AIR RATIO, POUNDS PER POUND
LEGEND
0.00166 sq. ft. area per port
0.003 sq. ft. area per port
0.006 sq. ft. area per port
TANGENTIAL VELOCITY AT RADIUS OF CIRCLE TANGENT TO THE PORTS, FEET PER SECOND

Fig. 10. Fuel-air ratio as a function of tangential velocity of gases above the fuel bed.

ratio of the tangential velocity to the linear velocity is plotted as a function of height of the ports above the fuel bed and the area of the tangential port. For any given height, it is evident that the energy losses involved in the transfer of momentum increase as the port area decreases.

In connection with the height of the ports, it was noted that the combustion efficiency was better with the uppermost ports, other things being equal. On the other hand, the burning capacity was somewhat lower.

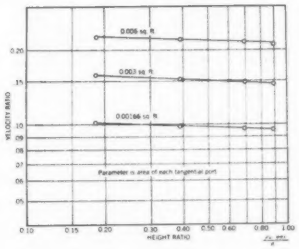

Fig. 11. Ratio of tangential velocity in combustion chamber to linear velocity of air in ports as a function of the area and height of ports.

Conclusions

Although a great deal remains to be done to evaluate the numerous variables associated with incineration, the results of the present study are conclusive enough for drawing the following general conclusions:

1. Low-ash, high-volatile wastes may be burned with high combustion efficiency in a cylindrical combustion chamber, by suitable selection of flow conditions in tangential air ports above the fuel bed. The vortex flow established in the chamber provides rapid mixing of the volatiles with oxygen and effective retention of particulate matter, particularly the larger sizes of char, which have a low terminal velocity and are normally so difficult to remove from the products of combustion.

2. The burning rate and the excess air are functions of both the air-mass flow rate and the dimensions of the tangential ports, and correlate with the Reynolds number of the air in the ports. Under optimum conditions the average burning rate of a batch of sawdust is about 6 lb./hr.-ft.^{2} grate area and the average excess air about 40 percent. The burning rate may be increased by controlled admission of undergrate air, although its use should be restricted to a relatively small fraction of the total air to avoid excessive discharge of smoke and tars, and by properly arranged refractory surface in the combustion chamber to provide greater radiant heat transfer to the charge.

3. The height of the ports above the fuel bed, other things being equal, affects both the combustion efficiency and the burning rate. Under the conditions of these tests, the changes resulting from varying the port height were not marked, but generally the combustion efficiency was highest with the uppermost ports, and the burning rate was highest with the ports close to the fuel bed surface.

It must be emphasized that the quantitative values given in this paper apply only to the stated conditions of the model tests. These conditions refer mainly to the kind of fuel used, the use of overfire air only, high heat losses from the shell, the absence of refractory in the combustion chamber, and batch operation.

At present it appears that satisfactory combustion can be accomplished in a single chamber. It is likely that for large incinerators natural draft generally will be insufficient to provide the energy necessary to establish the desired aerodynamic conditions in the combustion chamber.

Municipal Trash Disposal by Means of Controlled Open Dump Burning

By Paul MacMurray, Street Commissioner
Philadelphia, Pa.

Philadelphia, in common with most large American cities, is faced with the problem of disposing of the huge quantities of combustible waste produced daily by householders and commercial establishments.

Very little has been done in Philadelphia over the years concerning incinerator construction or dump facilities. The only new incinerator that we have was completed in the fall of 1951—the next newest was completed in 1923—and with the construction of the new incinerator, our incinerator capacity is still less than 600 tons, in spite of the fact that we are producing approximately 2600 tons of combustible material daily. As a result, over 2000 tons of material are burned daily on open land, both by the city itself and by private dump operators.

Practically no control was exercised over these operations in previous years. The old Department of Public Works had recommended year after year the construction of a number of incinerators for the destruction of this material in an orderly manner, not only because of the air pollution feature of the open dump burning, but because dumping areas were becoming scarce and we were being forced to haul the material greater distances year by year. It was feared that dumping space, at reasonable hauls, would soon be unavailable.

Although there has always been considerable objection to the open burning dump and the odors and smoke that are inherent in such operation, no real program of dump elimination was developed until the present administration took office. Mayor Clark, while serving as Controller, began a one-man campaign to clean up the dump situation in Philadelphia, and, in fact, made this an important issue in the political campaign of 1951, when he was the successful candidate for the mayoralty. In fact, I must admit that he was an annoyance to the members of the old Department of Public Works, who had charge of the dumping facilities and were endeavoring to make the best of a very poor situation. Upon election to office, Mayor Clark began a clean-up of the situation by the appointment of a new Air Pollution Control Board, of which Mr. Morris Duane is Chairman. Mr. Neville Chamberlain is Executive Director of the Division of Air Pollution Control. This group has been quite active, and rightfully so. We have now developed for Philadelphia a substantial incinerator program, which calls for the enlargement of the three present plants and the construction of two new plants, increasing our capacity from something less than 600 tons daily to approximately 2600 tons. The completion of this program will mean the elimination of the burning dump in Philadelphia. It is expected that the program will be completed in 1955.

Due to the work of the Air Pollution Control Board, all Philadelphians are much more conscious of air pollution than ever before and the Department of Streets, in its incinerator program, has obligated itself to meet more stringent requirements than we have ever considered in the past, as far as fly ash is concerned. The Board requires that dust in the gases not exceed 0.85 of a pound per 1000 pounds of gases adjusted to 12% CO_2 content. We have also obligated ourselves to eliminate odors by the use of special collecting equipment in the plants and by proper temperature control. Our specifications for incinerator work will require the contractors to guarantee that they will meet these requirements and to show ability to meet the requirements.

Production of combustible rubbish in Philadelphia has increased from 228 pounds per capita in 1948 to 346 pounds in 1952.

(Slide #1)

> "This slide indicates a comparison of the total production of ashes, rubbish and garbage in Philadelphia during the past five years. The ratio of increase in rubbish is probably the experience of most cities. You will note the greatly increased load of rubbish that must be destroyed.
>
> "This yearly rising per capita production is attributed to the increased wrapping and packaging of commodities and the use of frozen foods in cartons as against food products previously canned or bottled. The greatly accelerated use of gas and oil for household heating, especially since the war, has also had its effect. The percentage of rubbish formerly burned at all seasons of the year in coal furnaces, while an intangible quantity, is clearly reflected in the increased per capita production of rubbish.
>
> "Conversely, the per capita production of ashes has declined yearly."

In order to minimize the smoke and odor nuisance of the burning dump, during the period that the incinerator program is being developed and until we have sufficient incinerator capacity to eliminate the burning dump, strict controls were instituted on both private and municipal dumps. Specifically, this was accomplished as follows:

a. The burning of garbage on open dumps was eliminated. This was a particular source of annoyance because of the acrid fumes set up by the breaking

down of fatty acids at low temperature burning. An indication of this elimination may be had from the fact that, during 1952, a total of 6484 tons of garbage was delivered to City plants by private carters. Practically all of this material was formerly burned, with other refuse, on private dumps.

b. The elimination of burning at night and the proper control of burning during daylight hours were accomplished by rigid inspection and control.

The responsibility for the dumping operations in the past was divided among several departments. The city operation, of course, was controlled by the old Department of Public Works and the private dumping by the Department of Public Health. Since August of last year, the operation of all dumps has been under the supervision of the Department of Streets, which department succeeded the old Department of Public Works under the New Philadelphia Home Rule Charter. The regulations governing the operation of all city and twenty-eight privately owned and operated dumps are actually enforced by a group of five men—a field supervisor in charge (Mr. Joseph E. Osborne) and four dump inspectors, backed up by the Police Sanitation Squad. Twenty-four hour vigilance is maintained.

(Slide #2 to #5)

"These slides indicate conditions BEFORE and AFTER controlled burning was instituted on private dumps."

c. A method was evolved for the disposal of residual oils and other deleterious chemicals, by burial. This eliminated the previous practice of burning in the open which caused large billows of heavy smoke and bad odors. All such material is now handled at a single location.

The following slides indicate various conditions:

(Slide #6)

"Here we see a pool of waste oil dumped and awaiting match, before controls were inaugurated."

(Slide #7)

"This is what happens when oil and chemical residuals are ignited in the open."

(Slide #8 and #8-A)

"This slide indicates the present method of oil and chemical disposal, that is, dumping on the face of the dump—after which a cover of solid material is bulldozed over the oil and chemicals. "In this connection, I would like to point out that 22 out of a total of 28 private dump operators have procured bulldozers or similar equipment (as you see here) for the operation of controlled burning."

(Slide #9)

"This slide shows the method of controlled burning on the City dumps. You will note that loads are dumped short of the bank or face and are dispersed to permit quick combustion with a minimum of smoke."

(Slide #10)

"This slide shows the material being burned."

(Slide #11)

"Here you can see the material after it has been burned and as the embers are being quenched."

(Slide #12)

"This slide shows the ash residue being bulldozed over the cold bank."

(Slide #13)

"Air pollution from burning in the open, under proper control methods, will rarely exceed a density of greater than No. 2 Ringelmann and for only a comparatively short period of time."

In conclusion, I must again stress the fact that controlled burning is not a solution to a nasty problem. It is merely an interim and necessary measure until such time as adequate incinerator facilities are had.

Minimum Requirements and Regulations For Control of Private Dumps

1. All operators will be required to grade their dumps in order to present as nearly as possible a level area for dump operation.
2. Non-combustible and combustible material must be handled separately. Mixed loads, combustible and non-combustible, are not to be accepted on the dump. No garbage is to be accepted on the dump.
3. Combustible refuse to be burned shall be spread in an open area and burned completely. The dumping of combustible material over the dump bank will not be permitted.
4. Not more combustible material than can be burned in the hours permitted for burning shall be dumped in any one burning area. The material to be burned the following day shall be placed at a point as far removed from that day's burn as possible.
5. Industrial residue, such as chemicals, paints, and other materials which create objectionable odors and heavy smoke, shall not be burned. Special arrangements for these materials must be made to the satisfaction of the dump inspector.
6. Operators shall equip themselves with sufficient means to extinguish fires as will be necessary to handle the burning operation in the hours permitted for burning.
7. A dump operator or conductor shall be present at all hours that the dump is open.
8. All dumps shall have one entrance only, which shall be barricaded when the dump is closed.
9. The dump operation shall be conducted in such a way as to minimize smoke odors, the creation of mosquito areas, and rat infestation.

Discharge from Municipal Incinerators

By Robert L. Chass[a] and Andrew H. Rose, Jr.[b]

Disposing of garbage, non-combustibles and combustible refuse is one of the most perplexing problems facing urban life today. The more dense a population, the more disturbing is the problem. Many, many years ago, each family was responsible for the collection and disposal of its own refuse, the methods varying with the habits and needs of the individual group. As time progressed, and as the areas became more populated, society frowned on such unsanitary practices. This led gradually to the disposal of the material by private scavengers for a small fee. These early practices have since been refined and, in some cases, have resulted in large, profitable, private enterprises. Regularly scheduled collection of refuse by municipalities is of fairly recent vintage and has improved substantially the sanitary practices in the densely populated cities.

Statistics show that urban areas are continually becoming more populous. City dwellers are no longer satisfied with outmoded types of rubbish collection and disposal. There is urgent need for advancement. In some areas the installation and use of "backyard" type incinerators have failed to provide the necessary relief. A city population is usually too conscious of air pollution to accept this method as a solution to antiquated practices.

Industries, as well as commercial establishments, have always looked upon the disposal of their waste products as a necessary evil rather than a vital part of their operations. Because of this, the combustion equipment has been of the poorest and cheapest design. Not until recently has the pressure of air pollution control awakened industrialists, business men, governmental officials and residents to the need of replacing this antiquated equipment with properly designed incinerators.

Rubbish is created by all elements of a community—the industrial plant, the commercial establishment and the home. The industrial and commercial installation is usually a box type incinerator, required to burn several tons a day. The apartment house usually disposes of the material from its residents in a chute-fed single chamber incinerator. In some areas, especially Southern California, each home owner disposes of the material in a backyard type. The Los Angeles area differs from most of the rest of the country in that there is no need for the available heat from the destruction of this combustible refuse. Hence, there has been only one object in mind when an incinerator was designed—to get rid of the material.

Tests conducted by the Los Angeles County Air Pollution Control District show that for every ton of material burned in a commercial or industrial incinerator an average of 20 pounds are emitted into the atmosphere. For every ton of material consumed in a single combustion chamber wood burner, approximately 20 pounds are lost to the atmosphere. An average of 24 pounds of solids are lost to the atmosphere for every ton of material burned in a backyard type and 19 pounds for every ton burned in a chute fed type incinerator. It is estimated that approximately 125 tons per day of solid particles are emitted to the atmosphere daily from all types of incinerators in Los Angeles County.[1] This is much more than the Los Angeles atmosphere can bear.

Much has been said pro and con about municipalities engaging in the trash business. Some city fathers are rather reluctant to follow the example set by a few. Regardless of the feelings of individuals, it is now apparent that government must consider this matter in the same light as supplying the populace with fresh water.

Many surveys have been made to determine the quantity of combustible refuse contributed daily by an individual. The best available figures show that in Los Angeles County, with a population of 4½ million people, approximately 6,000 tons per day must be disposed of, exclusive of wood wastes.

A city has several alternatives to consider before choosing its course of action. The material may be collected by men and equipment employed by the city itself or the material may be collected by private enterprise, under contract with the city, to allow the city a hand in the control of the activities. The material may be disposed of in a cut, fill and cover site or in a properly designed and operated municipal incinerator. Either of these may be under contract with private enterprise. For those areas where cut, fill and cover sites are not available, the municipal incinerator is the only answer.

Once the decision has been made to erect a municipal incinerator, the first step must be to select a site for the incinerator. Because most of the present day municipal incinerators are *not* nuisance-free, no one wants the incinerator in their "back yard." This attitude on the part of the public must be overcome before construction can begin. No one will ever be content if smoke continues to pour out of the incinerator stack 24 hours a day.

The site selected must furnish ample space for the receiving and storage of two days' receipts. Provisions must be made for some segregation and drying of the material before charging to the incinerator. Additional ground must be provided for the disposal of the ash. If the incinerator is to utilize a water scrubber, provisions must be made for the handling of the resultant slurry. The entire area should be paved, fenced and properly landscaped. This will go far in reducing the complaints from the local citizens.

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AIR POLLUTION CONTROL DISTRICT—COUNTY OF LOS ANGELES

Results of Tests Made on Municipal Incinerators in Los Angeles County

TYPE OF MATERIAL CHARGED*	No. 1 A,B,C,D,E	No. 2 A,B,C,D,E	No. 3 A,B,C,D,E	No. 4 A,B,E	No. 5 A,B,E	No. 6 A,B,C,D,E,F	No. 7 A,B,D,E	No. 8**	No. 9
Lbs./Hr. Charged	8,550	9,500	9,500	7,700	8,400	7,200	9,000	12,000	11,000
Charges Per Hour	9	10	10	11	12	8	10	17	12
CFM	30,500	26,900	26,900	28,100	25,500	25,700	25,500		
SCFM	16,500	16,280	16,280	15,700	16,200	17,000	16,700		
Moisture—%	27.5	32.5	31.8	37.4	34.6	34.1	23.5	11.9	26.5
CO_2 (Dry)—%	6.2	6.0	8.9	8.7	8.3	7.4	6.9	5.5	7.9
CO_2 (Stack)—%	4.5	4.0	6.1	5.4	5.4	4.9	5.2	4.8	5.6
Gr/SCFM (Actual)	0.246	0.289	0.260	0.226	0.145	0.250	0.105	0.596	0.366
GR/SCFM (12% CO_2)	0.655	0.860	0.510	0.500	0.322	0.613	0.242	0.760	0.785
Total Loss Lbs./Hr.	34.8	40.4	36.3	30.4	20.2	36.5	15.0	82.6	97.9
Lbs. Loss/Ton Chgd.	8.15	8.50	7.70	7.90	4.86	10.10	3.34	13.80	17.80
Comb. Draft "H_2O	0.25	0.29	0.33	0.24	0.23	0.26	0.23	0.37	
Comb. Temp. °F.	1,600	1,540	1,560	1,710	1,750	1,720	1,470	1,790	1,540
Fan Temp. °F.		445	445	507	509	519	500		615
Stack Temp. °F		383	389	452	450	467	413	1,096	

*A—PAPER B—GRASS C—WOOD D—SHRUBBERY E—CARDBOARD F—SAWDUST.

**Plant consists of two units with a common stack employing natural draft. Remaining units employ induced draft.

Before selecting a site, there is an acute need for knowing what can be expected to be emitted from the incinerator. If the discharge of particulate matter is going to be substantial, locating such an incinerator in a residential area would be catastrophic. An entire program can be ruined by such a false start. Tall stacks are seldom the answer. Very little is known as to the exact discharge from municipal incinerators which are required to burn hundreds of tons daily of municipal trash. With this in mind, we would like to present the results of tests made on municipal incinerators located in Los Angeles County.

A study of the tabulated data indicates several salient facts which must be given consideration. The discharge of solid particulates to the atmosphere, prorated to tons of materials burned, must be taken into account first.

Municipal incinerator discharges, when the incinerator is designed employing the multiple chamber combustion principle, vary between 3.34 and 17.8 pounds of solids per ton of refuse burned. As indicated in the tabulation, two tests show results above 10.1 pounds and two tests show results below 7.7 pounds. These four tests are not considered as representative of the optimum performance of which the equipment is capable, should proper operation be employed or should the equipment be operated within its designed limitations. The average loss under normal optimum conditions, therefore, is 8.84 pounds per ton of material burned. Considering the two tests below 7.7 pounds as results which can be reached when certain design changes are incorporated, the average discharge under these ideal conditions is 4.1 pounds per ton burned. As previously given, the discharge of solids, for single combustion chamber incinerators, varies from 19 to 24 pounds of solids for each ton of refuse burned.

The reduction of solid contaminants discharged to the atmosphere which can be expected when the multiple chamber municipal incinerator operating under normal conditions is used, rather than the single, is 52 per cent. Under ideal conditions, when modifications of the equipment have been effected, this reduction can be expected to reach 77 per cent. Indications are that efficiencies somewhat in excess of this figure are possible.

The second fundamental consideration as evidenced by the test results is the effect of modifications of design on the reduction of atmospheric pollution. Tests 5 and 7, conducted by the Engineering Division of the Los Angeles County Air Pollution Control District, employed radical modifications in combustion air distribution. While it is realized that the equipment as it is now designed cannot be continuously operated under these conditions, it is felt that these tests are significant in that they indicate a definite trend towards improved combustion. It should be noted that the average discharge by this equipment when so operated was 4.10 pounds per ton as against the 8.44 pounds per ton under normal operating conditions. This is an effective reduction of somewhat in excess of 53 per cent. It was not possible to operate the incinerator continuously employing redistribution of combustion air due to the heavy formation of clinkers and excessive grate and stoker temperatures. However, it is important to note that at no time did the combustion rate fall below the designed capacity. These operating problems, while quite serious for the present design, can be overcome by redesign employing radical changes in the grate and stoker construction.

While a substantial reduction in the discharge was accomplished by changes in air distribution only, the studies indicate that additional gains can be made by a complete redesign of the equipment by applying those parameters necessary for better combustion using these principles of air distribution. Further tests employing these same principles of air distribution are to be run in conjunction with the engineering study on combustion now being conducted by the Air Pollution Control District's Engineering Division.

The third significant factor that must be taken into account is the opacities of the discharge. No significant correlation exists between either the total pounds of material discharged per ton of material burned, or the grain loading, and opacities. In an effort to determine the reasons for lack of a definite correlation, a series of tests were made to determine particle size distribution and volatilization characteristics of the solid materials in the effluent discharge. These tests showed that the total solids were 30 per cent by weight of particles less than 5 microns with the percentage of combustibles in this material between 4 and 10 per cent. Also, 24 per cent of the total weight of solid noncombustible materials were volatilized upon heat to 1600°F., with reduced percentages volatilized at the lower temperature ranges. This discrepancy in the correlation can, therefore, be explained in terms of these results. Slight variations in the relatively large per cent of 5 microns and less particles will cause large variations in opacities, particularly when the variations exist in the particle size range equivalent to the wave length of the visual spectra of light, that is, in the range of 0.25 to 0.8 micron. Since the percentage of the volatile noncombustibles varied with temperature, any fluctuation in gas temperature could cause some variation in the opacity of the discharge gas.

The materials collected from four of these tests were analyzed in the laboratory to determine the nature of the discharges. This sampling train consisted of a precipitator, six impingers and a Millipore filter. A spectrographic analysis of the material collected in the precipitator thimble showed as follows. The amount collected in the precipitator thimble represented 77.6 per cent of the total sample.

Large Amount	Very Small Amount (.x%)
Sodium.	Lead
Potassium	Titanium
Calcium	Zinc
Aluminum	
Silicon	

Small Amount (x%)	Traces (.0x to .000x%)
Magnesium	Barium
Iron	Strontium
	Lithium
	Copper
	Chromium
	Manganese
	Tin

A chemical analysis of the cations and anions showed:

SiO_2	20.6%	Cl	12.2
R_2O_3	10.4	SO_4	16.8
Ca	2.7	PO_4	14.0
Mg	4.7 (max., cal. on basis of SO_4)	NO_3	0.5
		Combustibles	4.2
Na	4.1		
K	13.3		

The precipitator condensate, or the material that was collected in the impingers, representing 22.3 per cent of the total sample, was also analyzed chemically. The results of these analyses were:

R_2O_3	2.2%	Ca	5.6
SiO_2	6.1	$Na+K+SO_4$	86.1 (by difference)

A Millipore filter used at the end of this sampling train collected the remaining 0.1 per cent of the sample. Visual inspection of the filter showed a moist stain in the area where the gases passed through. This stain did not disappear when put in a dessicator for several days. A microscopic examination showed a few scattered crystals. The stain did give a positive qualitative test for SO_4 which is an indication that it could be H_2SO_4. Since the weight of the material collected on this Millipore filter represented only 0.1 per cent of the total material collected, the actual amount present would be negligible.

The second of the four samples for chemical identification were taken using four impingers followed by a Millipore filter. The dissolved and undissolved material collected in the impinger train (84 per cent of the total sample) were concentrated by evaporating the free moisture to dryness at 110°C. The analysis of the cations and anions showed the following:

SiO_2	13.8%	Cl	15.2
R_2O_3	5.7	SO_4	24.1
Ca	2.5	PO_4	11.4
Mg	4.7	NO_3	0.4
Na	4.2	Combustibles	4.2
K	11.7		

This analysis compares favorably with that of the precipitator sample of the first test of this series. Even though the SiO_2 and R_2O_3 are lower, they appear to be in the same relationship to each other.

The Millipore filter which followed the impingers collected the remaining 16 per cent of the sample. The spectographic analysis of this material was as follows:

Large Amount	Very Small Amount (.x%)
Sodium	Magnesium
Potassium	Iron

Small Amount (x%)	Traces (.0x to .000x%)	
Calcium	Barium	Copper
Lead	Strontium	Chromium
Zinc	Lithium	Manganese
	Tin	Silicon

The third and fourth tests of this series were made using a Whatman thimble following four impingers. The small amounts of material collected in the Whatman thimbles in each test were not used in this analysis because it was impossible to accurately remove the material from the thimbles. The materials collected in all the impingers were combined for the following chemical analysis:

Analysis of Water Insoluble Portion

Water Insoluble Material	1.9608 grams	
Acid Soluble		0.1509 grams
Acid Insoluble		1.8099 "
Ash	1.2235 "	
Combustibles	0.5864 "	
Acid Soluble Analysis		
Iron	0.0671 "	
Calcium	0.0350 "	
Magnesium	0.0047 "	
Phosphorus	Present	

Analysis of Water Soluble Portion

Water Soluble Material (after drying)	4.1512 grams
Total Acid, as Sulfuric Acid	1.2315 "
Total Sulfates, as Sulfuric Acid	1.9659 "
Combined Sulfates	0.7344 "
Elemental Analysis of Water Soluble Portion	
Chlorine	1.1504 grams
Sulfates, as SO_3	1.6041 "
Nitrates	0.1537 "
Sodium	0.1794 "
Potassium	0.6966 "
Phosphorus	0.0174 "
Calcium	0.0631 "
Magnesium	0.0881 "
Iron and Alum., as R_2O_3	0.0475 "
Insoluble	0.0664 "

The total weight of the complete sample would thus be:

Total Dried Solids	4.1512 grams
Volatilized Chlorides	1.1504 "
Volatilized Nitrates	0.1537 "
Water Insoluble	1.9608 "
Material in Thimble	0.3340 "
Total	7.7501 grams

Many conclusions can be reached after studying the results of the above analyses. Some of the more significant ones are:

1. Approximately 20 per cent of the discharge is condensable, with approximately 5 to 15 per cent as SO_3.
2. Approximately 80 per cent is particulates containing silicon, lead, aluminum, calcium and iron. Since these constituents exist in the atmosphere in aerosol form, they contribute to the reduction in the visibility. It has been shown that as the visibility decreases in Los Angeles County, the particles in the 0.5 to 0.8 micron range increase more rapidly than in other size ranges.[2]
3. Approximately 2/3 of the total sample collected is water soluble.
4. Approximately 30 per cent by weight of the sample is below 5 microns in size.
5. Approximately 4 to 10 per cent of the solid particulate matter is combustible.
6. The solids emitted into the atmosphere from properly designed municipal incinerators can be as much as an 80 per cent improvement over that from backyard types.

While the compiled engineering and chemical data are adequate to allow manufacturers of incinerators to make design modifications which will result in substantial reductions in incinerator emissions, these studies further indicate that even greater gains are possible. Improved municipal incinerator design necessary to meet ever-increasing demands by both the public and control agencies can only be accomplished through sound engineering research.

[1] L. A. Co. Air Pollution Control District. Inspection and Engineering Reports.
[2] L. A. Co. Air Pollution Control District. Second Technical and Administrative Report on Air Pollution Control in L. A. Co., 1950-51.

Municipal Incineration in Baltimore

By William P. Fannon
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Baltimore has an area of 91.9 square miles and a population of 960,000 persons. The average pick-up daily—90,000 stops; average daily quantity—1200 tons of mixed materials.

Responsibility

Charter Provision—Section 75 of the Baltimore City Charter (amended to 1949) specifically places responsibility upon the Bureau of Sanitation for the cleaning of streets, and the collection and disposal of garbage, ashes, refuse, trash and other waste matter. This section states that the Sanitary Engineer shall direct the operations of the Bureau, and shall perform, subject to the authority of the Director of Public Works, the duties and exercise the powers which are therein imposed or conferred upon the Bureau of Sanitation.

History of Disposal Practices

1. *Practice in Baltimore up to January 1, 1952*—Until January 1, 1952 Baltimore was one of the few cities, if not the only large city, in the United States in which refuse collection and disposal operations were not under single direction.

2. *Administrative Action Transferring Disposal Operations to Bureau of Sanitation.* The present Administration, by action of the Board of Estimates on November 2, 1951, terminated the management contract of the Foreman Company, which had been in operation since the end of the original contract for construction and operation of No. 3 Incinerator, one of the most conspicuous examples in the country of contractor's financing of a municipal disposal plant, and placed responsibility for the operation of the Plant with the Bureau of Sanitation.

3. *Historical Reasons for Previous Arrangement.* There were very good historical reasons for the previous arrangement, dating back to the building of the old No. 1 and No. 2 Incinerators in Baltimore City when it was considered that the personnel of another Bureau was more qualified to operate them than the personnel of the Bureau of Street Cleaning; the practice was not changed when No. 1 Incinerator was discontinued upon completion of No. 3 Incinerator, and it was also natural for the direction of the operations of No. 3 to be taken over by that Bureau upon expiration of the original contract for construction and operation of No. 3.

4. *Advantages of Consolidation of Responsibility for Collection and Disposal Operations under the same Bureau Head.* In the nearly two years since direct responsibility for all collection and disposal operations has been placed in the Bureau of Sanitation a decided improvement has been noted. All operations—both collection and disposal—are better coordinated. This has produced definite economies and has stimulated the morale of collection and supervisory forces.

This also has promoted the planning of new garage locations for all Bureau of Sanitation truck equipment and labor personnel. It is the intent to locate collection and street cleaning forces at the two Baltimore incinerators, namely, No. 3 and No. 4, which are located on the outskirts of the city, so that all operations can start and

stop from these properties. The present garage locations are located in the heart of the densely populated areas of Baltimore and cause considerable inconvenience getting to and from their work operations, as well as being a detriment to the already heavy city traffic. Traffic-wise the relocation of these garages will be most advantageous.

Disposal Methods

1. *Resume of Methods Employed in Baltimore Prior to Incineration.* Prior to the adoption of disposal of municipal waste by incineration in Baltimore various methods were employed to accomplish this important phase of public service. For instance, hog feeding, burial, grinding, composting and reduction methods had been utilized in the disposal of garbage, and the open dump for the disposal of rubbish.

2. *Earlier Incinerators in Baltimore and Results Obtained.* Incinerators for disposal of rubbish had been in operation in the years prior to the construction and operation of No. 3 Incinerator. The No. 1 Incinerator was discontinued in 1933 upon the opening of the No. 3 Plant and No. 2 Incinerator since 1944 has been operating on a standby basis only. The first plant disposed of 125 tons per 24 hours, and No. 2 plant 250 tons per 24 hours, both rubbish only.

3. *Design and Type of Present No. 3 Incinerator.* No. 3 Incinerator is a 600-ton plant for the destruction of both garbage and rubbish. It was designed and erected by the Pittsburgh-Des Moines Steel Company, and is known as the Pittsburgh-Des Moines Multiple-Cell-Mutual assistance type furnace. The furnace was designed on the basis of 65% garbage and 35% rubbish by weight, and the capacity being 600 tons per 24 hours. It is a pit and crane type plant, the refuse pit is 16′x16′x200′, storage capacity 1900 cubic yards. There are two 3-ton traveling cranes, each equipped with a 1½ cubic yard clam shell bucket which charges the refuse into 16 charging hoppers.

There are 4 furnaces with four cells each, and each cell is equipped with a louvre air control. The forced preheated air is supplied by a 10,200 cubic feet per minute blower, which passes the air through a cast iron tubular preheater. Each cell has a dumping section of grate and the ash residue is dropped through into an ash hopper equipped with segmental ash gates. The ash tunnel is designed for a truck to back in and receive the ash from the ash hoppers. Each furnace has a combustion chamber 5′x20′x19′—two chimneys 142′ above the grate line and 9′0″ inside diameter.

4. *Density of Smoke, Odors, Gases, etc.* Upon completion of the plant, the constructor guaranteed:

> "That, when any or all of the furnaces of the plant are in normal operation, there shall be no smoke at any time escaping from the chimneys of a degree of darkness or density greater than that determined by Chart No. 1 of Ringelmann's Smoke Scale, as standardized by the United States Bureau of Mines."

These guarantees have held through the years.

Recent Improvements

1. *Installation of Automatic Stoker.* Immediately after the transfer of disposal operations to the Bureau of Sanitation, a new type grate was installed in number two furnace at the No. 3 Incinerator as an experiment. This experiment proved without question that the installation of this grate increased the burning capacity of the furnace approximately 50 tons per day. Also, it eliminated the requirement of separation of tin and glass. This indicated a savings in labor, an increase in actual burning time, and a material reduction in furnace maintenance costs. After fully testing this grate, three additional hydraulically operated stoking grates were ordered and installation was completed in mid-April of this year.

2. *Principle Automatic Stoker.* In the installation of this mechanical stoking device the raw refuse is charged at the bridgewall end of the grates. This is the customary fashion for mutual assist furnaces made by the Pittsburgh-Des Moines Company. However, the grates have been set at an angle of about 15½ degrees from the horizontal with the portion of the grate at the back of the furnace higher than the forward end. Each individual grate section is hinged at the lower side and has a curved shield at the upper side so that it can be rotated through an angle of about 60 degrees without getting burning refuse clogged in the rotated portion.

The grate sections are moved alternately by hydraulically powered lever bars. Every other grate section will be raised while the remainder stay in place. This alternate moving provides uniform and regular agitation required to complete the drying process and advance the material down the grates as rapid burning takes place and new surface is constantly exposed for combustion.

This constant agitation, in addition to aiding the burning operation, has a tendency to prevent clinker formation. Actually our tests showed that clinkers were almost non-existent. Those few small clinkers which did form were not on the wall or the grates but in the moving body of refuse that worked down to the dumping section and did not interfere with normal operation.

The agitation allows the operator to advance the burning material on each individual section according to its burning characteristics. Thus assuring complete reduction. The non-uniform consistency of the raw refuse demands this flexibility to obtain maximum efficiency and deliver a completely sanitary ash.

The residue deposited upon the dumping section has been burned down thoroughly; and by means of the power cylinder provided, the grates can be dropped, allowing the ash and noncombustibles to fall into the ashpit.

The furnace dimensions are 29 feet in width by 8½ feet in depth, giving us a horizontally projected grate area of

approximately 246½ square feet. Based on the test figures of 189.6 tons of refuse per 24 hours, this results in a combustion rate of approximately 64.2 pounds per square foot per hour. These figures are the result of a 72-hour test conducted by our department at the end of a 90-day trial period.

From this test, we arrived at the following conclusions: First, we have noted that the grate arrangement has given us an increase in furnace capacity. This has been in the order of 50% over the actual capacity that the old furnaces were able to operate at, and 26½% over the original rated capacity of the furnaces.

The second advantage is the curtailment of stack nuisance. By being able to maintain constant furnace temperatures, even while cleaning the fires, it is possible to reduce to the point of elimination odors and smoke, fly ash, mist, and other visible discharges from the stack. The critical temperature in the elimination of these items is approximately 1,300 degrees F. We were able to keep temperatures above this point easily. The elimination of these nuisances means that we should be able to locate new plants closer to built-up areas without danger of objection. This will shorten our hauls and reduce collection costs.

The total installation for all of the furnaces was less in cost than $100,000, and has increased the plant capacity from a rated 600 tons per day to 800 tons plus per day. By way of comparison, the average cost to build a new incinerator today will run approximately $3,000 per ton. It can thus be seen that a complete new installation for the 200-ton increase would cost in excess of $600,000 for the plant alone, and this is not taking into consideration the cost of the labor necessary to man such a plant nor the maintenance normally expected on such a project. Therefore, this shows a savings of better than $500,000 and the plant will be operated with no additional personnel.

Quantity and Costs

1. *1952 Tonnages and Types of Materials Disposed of at No. 3 Incinerator.*

Material	Tons
Mixed Refuse:	
City	120,320.120
Private	46,465.705
Street Dirt	2,104.520
Market Refuse	10,528.830
Dead Animals	346.910
	179,766.085

2. *Salvage Returns*
   Salvage Revenue for 1952—$28,062.79
3. *Operating Costs*
   Net Operating Cost for 1952—$272,829.40
   Unit Cost—179,766.085 Tons—$272,829.40—$1.52 per ton.

Proposed New Incinerator

1. *Type of Incinerator Proposed.* Contract has been awarded for equipment similar to that described herein and plans for the building are in process of completion. The new incinerator will be known as Incinerator No. 4 and located on Pulaski Highway at North Point Road.

Financing-Estimated Cost. The estimated cost will be approximately $2,000,000, which will be financed by municipal loan.

Some Principles in The Design and Operation of Municipal Incinerators

By William S. Foster
Engineering Editor
The American City Magazine

The engineering profession has a lot yet to learn about that branch of sanitary engineering generally known as incineration. All of us feel our way cautiously and with a great humility, because no sooner do we see a set of standards established, than we also see them toppled by some enterprising engineer or operator who casually violates our cherished principles and makes the violation work.

The manner in which we feel our way probably is well illustrated by the two little girls who were discussing the progress they had made in their Sunday School assignments.

Said one, proudly, "We've reached Original Sin."

"That's nothing," boasted the other. "We're past Redemption."

A lot of us certainly have seen refuse sanitation programs that gave all the appearance of original sin. Fortunately, neither man nor a refuse sanitation program ever is past redemption. We will willingly leave the redemption of man to others more capable than ourselves and be content if this discussion helps in the redemption of suffering incinerator programs.

Incinerator Functions

First, let us try to visualize clearly what an incinerator is supposed to do. As I see it, an incinerator performs two basic functions:

1. It reduces the volume of the refuse that a city must cast away.

2. It transforms the refuse into an inert, inorganic residue that causes no nuisances or health problems.

Some of the most frequent complaints about municipal incinerators is that the residue, or ash, that it discharges, is "sour." This means that the incinerator merely burns the easily combustible material, and then toasts the remainder. The putrefying organic matter still remains to create odors, attract insects, and make a haven for rats. Thus it fails in its appointed task of protecting the health of the community.

Some have argued that this residue can be delivered to a sanitary landfill for disposal. In my opinion, this is only an excuse for faulty design and indifferent operation. If a municipality has plenty of space for a landfill, then it will be money ahead to use that method. Municipalities use incinerators because land costs are high and disposal areas are at a premium. In general, I see no merit in wasting valuable disposal space by half-burning the refuse and then disposing of it in a sanitary fill that, at best, requires a substantial amount of land to operate as it should.

What Is Municipal Refuse?

Next, let us try to visualize what municipal refuse is. At one time designers considered refuse a mixture containing 65% organic garbage and 35% other rubbish. Today, the popularity of packaged foods has eliminated much of the waste that the housewife used to throw into the garbage can. Moreover, the advent of the kitchen garbage grinder is also reducing the volume of organic garbage. In Washington, D. C., W. A. Xanten, Superintendent of Sanitation, finds that garbage now constitutes only 5% of the total refuse production. In the Los Angeles area, a study showed that refuse consists of 7% garbage by volume or about 16% by weight.

This means that today's incinerator receives much more burnable material and has less wet, putrefying garbage to handle. Nevertheless, one has to appreciate that an incinerator must be rugged enough to receive a load of wet, spoiling potatoes, or a concentrated mass of wet market waste if the occasion arises. At the same time, it must be versatile enough to control the intense heat that will be generated in today's light refuse containing paper, cardboard cartons, and the many other burnables that are discarded by homes and industries.

Next, we must estimate how much refuse an incinerator will have to receive. If a municipality has been alert enough to keep records of collection work, it will know this very accurately. Greeley and Hansen, Chicago consulting engineers, used a figure of 560 pounds of refuse per year per capita in the design of the Winnipeg, Canada, incinerator. Louisville, Ky., a few years ago, discovered that it was collecting 2.23 pounds of refuse per day per person. New York City has designed its incinerators to receive refuse at the rate of 2.7 pounds per person per day, and has estimated that it will have a calorific value of 4,000 BTU per pound. All cities, except New York City, exclude ashes from the refuse. However in New York City the ash problem is not serious.

Now let us assume that you know how much refuse you have to collect, what it is like, and would like to design the plant to burn it. What sort of a plant should you build?

Storage Pit

You first must decide how your plant will handle its refuse. And this means that you have to choose between the uses of a storage pit with its crane to charge the furnaces, or the use of a direct, floor charging arrangement. This choice isn't difficult.

A storage pit gives your plant greater flexibility of operation. It runs up your operating cost, but can cut down on the cost of your furnaces. In general, a plant that uses a storage pit is not quite as hazardous as one that charges the refuse directly from the floor. Once in a great while a man falls into the furnace when the refuse is dumped directly on the floor.

Incinerators are generally rated in terms of the amount of refuse its furnaces can burn in 24 hours. However, the trucks will arrive at the incinerator on an irregular schedule over a period of 6 to 8 hours. If these trucks deliver, let us say, 50 tons in a 6-hour period, and you charge them directly from the floor, then the furnaces must operate at the rate of 200 tons per 24 hours.

With a storage pit, the trucks can discharge their loads as fast as they arrive, and the crane operators can transfer it to the furnaces in a more orderly manner. The incinerator can be operated for two shifts, or 16 hours if desired. This would mean that the furnaces would have to operate only at the rate of 75 tons per 24 hours to do the job. Thus furnaces of less than half the size can be used successfully with a storage pit. Obviously, you can reduce the size even further if you operate the incinerator for a full 24 hours.

If you charge the furnaces from the floor, you have a simple operation. One or two men on the charging floor plus one or two men on the operation floor will probably do the work satisfactorily for incinerators with rated capacities of 100 tons. If you use a crane and storage bin, you must increase the size of the building and often hire a crane operator. These men are skilled and command a salary commensurate with their skill.

Generally, the design of an incinerator places the storage pit directly in front of the furnaces. Even in the smaller incinerators we generally find two furnaces, and the storage pit will be placed with the long side adjacent to them. Thus one needs a bridge crane able to move in two directions to keep the furnaces charged.

Push Button Operation

One way of eliminating the cost of a bridge crane and the expense of a skilled operator has been developed by Henry W. Taylor, New York City consulting engineer. Mr. Taylor, in his smaller incinerator plants, places the furnaces in line with the centerline of the storage pit's long axis. In this way, if the pit is not excessively wide, a crane on a monorail can take the refuse from the pit to the furnaces. These cranes can be operated by a push button, and, in general, do not require skilled operators.

Mr. Taylor developed an extra refinement in this "straight-line" operation of incinerators at his Darien, Conn., plant. He designed the facilities to handle the incinerator residue with a hydraulic jetting device that transferred the residue to a storage pit beyond the furnaces. The monorail crane can pick up the residue and place it in the trucks for transfer to its disposal point, thus allowing the crane to perform an additional task, and avoiding the need to make the building deeper to receive the conventional residue hopper.

Nevertheless, a floor-dumping plant, if it has ample furnace capacity, is a simple, straightforward way to handle the design. Its furnace capacity, rated in tons per 24 hours, probably should be four to five times the anticipated peak daily load that the plant will have to handle.

If the refuse load delivered to the plant is fairly consistent, not subject to unusual fluctuations, and your labor costs are high, then such a plant offers possibilities. However, if the volume of refuse has a tendency to vary, increasing as time goes on, and if it is more economical to use extra shifts than to purchase greater furnace capacity, then the crane-and-bin type of design should get the nod. There are no rules of thumb to guide you in these matters. The best way is to take a pencil and a piece of paper and figure them out.

What Type of Furnaces?

At this point we have the refuse delivered to the plant, ready to be received by the furnaces. What sort of furnaces should we provide?

This requires us to reconcile the narrow, unwavering path of the theorist with the broad and often wandering trail of the practical man. This presents the opportunity of relating the difference between these two men, so often seen in the technical field.

A theorist, we have been told, is one who knows where he wants to go, but doesn't know how to get there. A practical man is one who gets there and finds that he is in the wrong place.

There are one or two other definitions with just enough truth in them to be worth remembering when analyzing this and other growing engineering fields.

For example, we have been told that an engineer is a man who makes an assumption and applies a factor to it. How true, unfortunately. Again a prejudice is a principle that, when we defend it, we get mad. Would that we had the wisdom always to separate unwavering principles from transient prejudice.

Proper Design

With these sobering thoughts in mind let us appraise the factors we commonly use in incinerator design.

For many years, the most popular furnace was the rectangular, mutual assisting cell-type design. Most supplied a burning rate varying from 50 to 70 pounds per square foot per hour on the grates. This type, incidentally, is still preferred by many communities.

However, these furnaces require stoking by hand. This is arduous work, requiring a good deal of manpower. So the manufacturers have developed self-stoking arrangements that eliminate this need. Currently, the designs most popular are prepared around a cylindrical furnace with a rotating cone and stoking arms mounted on the grate. Forced air enters the burning refuse through the cone and the grates; the arms in turn keep the mass loose

to encourage burning. The Nichols Engineering and Research Corporation and the Morse Boulger Destructor Company, both of New York City, offer designs based on this circular, mechanically stoked type.

In addition, there are other types that supply a self-stoking feature, but can be fitted to a rectangular furnace. F. O. DeCarie, Los Angeles, has developed a two-level furnace. The refuse first drops onto an upper grate that has large rotating teeth. Here, the initial burning takes place, then the teeth of the grate open, allowing the refuse to drop to the lower grate to complete the burning. The design appears interesting, and engineers are looking forward to more operating data which undoubtedly will be available as time goes on.

Another very interesting self-stoking device for the rectangular furnace is the inclined grate developed by the Flynn and Emrich Company of Baltimore. With this type, stoking sections of the grate rotate upward in alternate rows to stir constantly the refuse and work it down the slope to the dumping grate. Reports received thus far are very encouraging.

Specifications Important

However, regardless of the specific make of furnace, every engineer would like to know what sort of specifications he should write to get a good, workmanlike furnace and yet be fair to all manufacturers. If he simply asks them to design to their own standards a furnace, able to burn the refuse "thoroughly and satisfactorily," he must reconcile himself to the fact that he forces the manufacturers to make their proposals as lean as possible, hoping that the furnace supplied will meet these rather ambiguous requirements.

If, on the other hand, he can refer exact standards for furnace design, then he places all designers on the same footing and removes much of the uncertainty from the work.

One point is the furnace grate area. In times past, this requirement has been placed at 50 to 70 pounds of refuse per square foot of grate area per hour of operation. On the basis of present operating figures, I believe that this range is good for the rectangular, mutual-assist type of furnace, even when equipped with self-stoking devices.

The cylindrical types appear to produce good operating results with grate areas that are reported to vary from 85 to 100 pounds per square foot per hour. However, and this is very important, these designs do not count the area covered by the stoking cone as grate area. If it were considered in this category, probably both types would have the same grate-area factor. However, since it isn't, for this type. If I were doing the designing, I would feel much more safe by restricting my specification to the lower limit of 85 pounds.

The volume of the furnace, or the ignition chamber, as it is often called, next requires attention. For all types, this seems to vary from 7½ to 11 cubic feet of volume per ton of rated capacity. The figure of 7½ cubic feet seems low; in my opinion, a figure of 9 cubic feet would be better, and 11 cubic feet would be wise if the refuse is preponderantly burnable rubbish. The operators must exercise caution, however, when placing the refuse in the furnace. A strong possibility exists that they will charge it too heavily and interfere with the burning.

Combustion Chamber Design

The next essential point is the combustion chamber, generally located outside of the furnace itself. All designs seem on a figure of 15 cubic feet per ton of rated capacity, and all seem to give satisfactory service with this design.

The next consideration is the expansion chamber. In this chamber, the gases begin to be slowed enough to drop the heavier fly ash. Apparently an estimate of about 12 cubic feet of volume in the chamber per ton of rated furnace capacity does this job very well; unless special air pollution standards exist. We will discuss this a little more in detail later.

Regarding the stack sizes, the figure is commonly set at 0.25 foot per ton of rated capacity per 24 hours. The height of the stack may run from 75 feet for a 30-ton plant to 175 feet or higher for a 300-ton plant. The stack is an obvious and easily identified object, thus making the incinerator subject to criticism by those who like to find fault. Henry W. Taylor designed the Hempstead, N. Y., plant with short, inconspicuous stacks, supplying them with induced fans to help discharge the stack gases, very effectively disguising the appearance of the incinerator.

Air for furnaces is another fundamental point. One fairly useful figure is 5 pounds of air for each pound of refuse incinerated. This probably should be increased if the refuse is high in combustibles.

Operating temperature is another point that bears attention. Garbage has a reputation for producing bad smells. Since incinerators are associated with garbage, the public accordingly associates incinerators with smells. The public sees the stacks, knows that the incinerator is there, and soon is sure that the gases leaving the stacks have offensive odors.

If the temperature in the combustion chamber remains consistently above 1200°F, this odor problem cannot exist. Most unpleasant odors arise mainly from fatty acids which break down at temperatures around 800°F. Hydrogen, also in the refuse, ignites at 1100°F; carbon monoxide and methane at 1200°F. With present refuse, containing its high content of combustibles, most incinerators have no particular difficulty meeting this standard. In fact, many engineers work to keep the temperatures down.

The factor of air pollution from incinerator stacks is one that seems troublesome. In most localities, a simple specification based on the Ringelmann chart is enough of a safeguard. However, as we all know, a standard based fundamentally on color is not very good except from a psychological standpoint. A lot of pollution can enter the

atmosphere and cause trouble that won't color the smoke enough to raise a danger signal on the Ringelmann chart.

Therefore, we find air pollution engineers journeying to the mechanical engineers for guidance, turning to their standards for coal-fired furnaces. Among these is the specification that the discharged gases should contain no more than 0.85 pound of solids per 1000 pounds of gases. I believe that the incinerator industry is ready to meet this specification. But then we see the requirement that this must be on the basis of 50% excess air or 12% carbon dioxide in the gases. I have learned that this is the normal operating condition for coal-fired equipment, but is not normal for incinerators. I readily admit that I could be wrong, but as I see it, these requirements do not help the air pollution condition nor the incinerator designer. I would like to see it written out of these specifications.

As I understand it, incinerators operate on a 3 to 6% carbon dioxide content in the gases for highest efficiency to control temperatures, while coal boilers operate best at the 12% carbon dioxide content previously mentioned. This has the effect of reducing the allowable suspended solids loadings to a figure between 0.2 to 0.4 pounds per 1000 pounds of gases.

Assuming, however, that you wished more solid material removed from the stack gases than 0.85 of a pound referred to previously, then you may have to use one of the mechanical appliances, but these can be rather expensive if you plan to take out the extremely fine solids. In one instance that was brought to my attention, the cost of the appliances equalled the cost of the furnaces. Electrostatic devices apparently do not work well at temperatures above 800°F.

Water Sprays

Another system that has seen some use on the west coast is that of using water sprays. Some advance the theory that the fine droplets of water in the expansion chamber act as a kind of flocculating agent that traps the fine particles that otherwise would go up the stack. The fact that this water has to exist in an atmosphere of from 500° to 800°F illustrates that the water requirements will be heavy. One estimate is that roughly 400 gallons of water will be required per ton of refuse burned.

One obvious value that such an arrangement provides is that it cools the gases, therefore reducing the volume and slowing its passage through the chamber; this allows more solid matter to drop away. There may be figures showing how effective these sprays are in removing solids from the gases. If they are available, I would be grateful for the opportunity of reviewing them.

There are other ways of cooling the gases in the expansion chamber. The heat represents useful energy that occasionally can be extracted and put to work. Some incinerators pass the gases through boilers and generate steam used for heating and power. Some place preheater tubes in the chambers. These tubes form passage ways for the air used in the forced draft system of the furnaces. If the air is hot when entering, the burning can be expected to be improved.

The sanitary engineering field has other types of furnaces at its disposal also. One is the big Volund design in which the burning proceeds inside an inclined rotating barrel. This has the advantage of continuous feeding. The only installation is at Atlanta, Ga., where it does a very thorough job of burning, and, in the process, develops steam that it sells to a local power company. This and other income-producing features make the plant virtually self-supporting. It currently is being sold by International Incinerators, Inc., of Atlanta. The company officials tell me that it is useful primarily in the great cities, probably with a population of 250,000 or more.

Chain-Grate Principle

New York City has an interesting incinerator built around the chain-grate principle, and its nearby suburb, Englewood, has used an incinerator of this type for many years. However, the many movable parts in a chaingrate design has never made them popular.

This covers some of the fundamentals as I see it. Know your refuse, understand your operating conditions, and from this understanding, decide whether you will be served better with a plant using a storage pit and crane, or one that charges its refuse directly from the floor. Give your manufacturers some standards to use when building their incinerator, such as grate area, furnace volume, combustion chamber volume, and expansion chamber volume. Finally, adopt a practical attitude toward the possibility of air pollution from the stack gases. Remember that the incinerator is not burning a consistent fuel under controlled conditions, but a wonderfully inconsistent product charged through a door four feet square that opens frequently.